Vincent Obias *Editor*

Robotic Colon and Rectal Surgery

Principles and Practice

Springer

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This book is dedicated to all of the surgeons who are courageous enough to thoughtfully utilize a new technology or technique to improve the outcomes of their patients, to question these advancements, to critically review and publish their results, and, once these surgeons are comfortable with their mastery, to continue to innovate and try new ideas.

Foreword

Issac Asimov's Three Laws of Robotics

1. *A robot may not injure a human being or, through inaction, allow a human being to come to harm.*
2. *A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.*
3. *A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.*[1]

Robotics, in its current form, is not the robot from fiction and movies. Rather, it is a mechanized computer interface that augments a surgeon's innate abilities. Robotic surgery is a natural continuation of minimally invasive surgery that was pioneered by laparoscopists and endoscopists. As has been the case in many instances in science and industry, the advent of robotics has disrupted the status quo and has helped move the field of surgery forward. At its base, robotics is a mechanized computer interface between the surgeon and the patient. However, instead of separating the patient from the surgeon, robotic draws the surgeon closer with incredible 3D views and fine wristed instruments. As technology continues its exponential pace, future iterations of robotic platforms will look radically different from what we have used as pioneers, but the basic surgeon-computer-patient paradigm will always be there.

It is with great pleasure that I introduce the reader to the first edition of this textbook. The genesis of this textbook was rooted in the realization that current robotic colorectal textbooks were being written and edited by surgeons who did not do robotics. All of the main authors in this textbook have done over 100 robotic colorectal procedures and are experts in the field. They truly support and endorse robotics in colorectal surgery and their enthusiasm shines through in the chapters they have written.

Thank you for reading this textbook. I hope you enjoy this labor of love.

Vincent J. Obias, MD, MS, FASCRS, FACS

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[1] Asimov, Issac, *I, Robot*. 1950.

Contents

Chapter 1
Introduction: The Evolution of Minimally Invasive Surgery

Jeremy L. Holzmacher and Samir Agarwal

Perhaps the most invigorating and daunting challenge to the modern day surgeon is the continual drive to push the envelope of what is innovative, fast, and cost effective. Likewise, surgeons must at all times maintain patient safety and provide treatments that are as efficacious as the current standard of care. As surgery began forming into a cogent specialty in the late nineteenth and early twentieth century, foundational strides were made in advancing antisepsis and sterility along with updating the current body of anatomic knowledge. Around this same time, the developing interest in the basic sciences lead to the birth of the surgeon scientist who formally set to define the pathological basis for surgical disease. William Stewart Halsted was one of the key figures in removing the general surgeon from the paradigm of the surgeon barber of the 1800s into the surgeon scientist of the twentieth century. This was part and parcel to his pursuit of the scientific of surgical diseases, and in many respects set the tone of translational research from the laboratory to the operating room. Of course, his achievements were built upon meticulous and often tireless efforts of the great surgeons that came before him. Physicians who explored nearly every cavity, crevice, and orifice of the human body and for whom so many eponyms exist.

As the century progressed, a wave of new technologies began surfacing which would come to empower both diagnostic and therapeutic medicine. Henry Dakin and Nobel laureate Alexis Carrel did extensive research into wound management during World War I, leading to major advancements in wound healing by experimenting with antisepsis solutions and the evolving practice of debridement and irrigation. By World War II, most of the foundations for basic operative procedures had been established and the subsequent growth of surgical procedures from the

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1940s onward became nearly exponential. Diseases, which were lethal only decades earlier, could now be treated in a precise and nuanced fashion. The modern era of major open surgery had come, it was radical in breadth and scope, and the evolution of surgery as a field had only begun.

The Dawn of Endoscopy

While open surgery dominated as the sole intervention for surgical disease for the majority of the twentieth century, concurrent advances in catheter-based and endoscopic technology set the foundation for what would become minimally invasive surgery. In their infancy, however, minimally invasive approaches were largely regarded as ineffective for interventional means. Indeed, the adoption of minimally invasive procedures like endoscopy by thoracic and abdominal surgeons was delayed largely by two key factors: (1) endoscopy was deemed inferior to the gold standard of open surgery, especially when dealing with enclosed intracorporeal cavities; and (2) the technology of endoscopes was limited by their lack of video-imaging capabilities, high definition visualizations, and insufficient lighting for the operating surgeon and their assistants to perform meaningful maneuvers. Consequently, surgeons sparingly performed endoscopy leaving a vacuum through which other specialties would advance the field. The toils and triumphs of these pioneers are as expansive as the achievements of the great major operative surgeons of the time.

Kurt Semm, a gynecologist, succeeded in developing an electronic insufflator with trocar systems that allowed introduction and removal of instruments without losing intra-abdominal pressure, and his performance of the first laparoscopic appendectomies (Figs. 1.1 and 1.2). The radiologist Benjamin Orndoff began experimenting with “peritoneoscopy” and was able to establish pneumoperitoneum using an intraspinal needle by insufflating oxygen. Similarly, Janos Veress developed a modified intraspinal needle to instill pneumothorax for the treatment of tuberculosis, later to be adopted for introduction of pneumoperitoneum (Fig. 1.3). George Kelling, a gastroenterologist, experimented feverishly with methods of insufflation and insufflating gases, as well as conceptualizing and describing the beginnings of what would ultimately become modern day laparoscopic instruments (Fig. 1.4). A true endoscopist, George Berci of Austria led advances in miniaturizing video-imaging technology within endoscopes and improving endoscopic illumination, setting the stage for high definition televised laparoscopes for visualizing intracavitary anatomy (Figs. 1.5 and 1.6).

Surgery via laparoscopy, however, was not first successfully performed until the early 1980s by European surgeons using their own personal techniques for cholecystectomy. The legitimacy of endoscopy became solidified in 1987 when the French physician P. Mouret who performed a four trocar laparoscopic cholecystectomy successfully in a young woman.

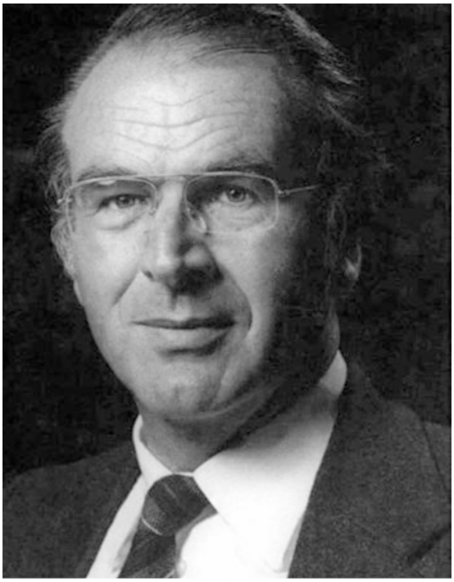

Fig. 1.1 Kurt Semm (1927–2003)

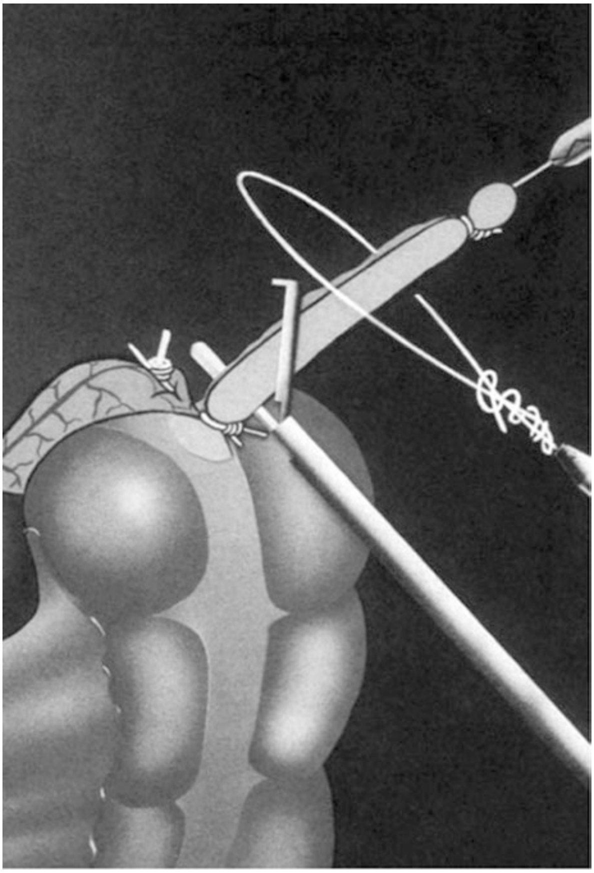

Fig. 1.2 Kurt Semm's diagram proposing a laparoscopic approach for an appendectomy

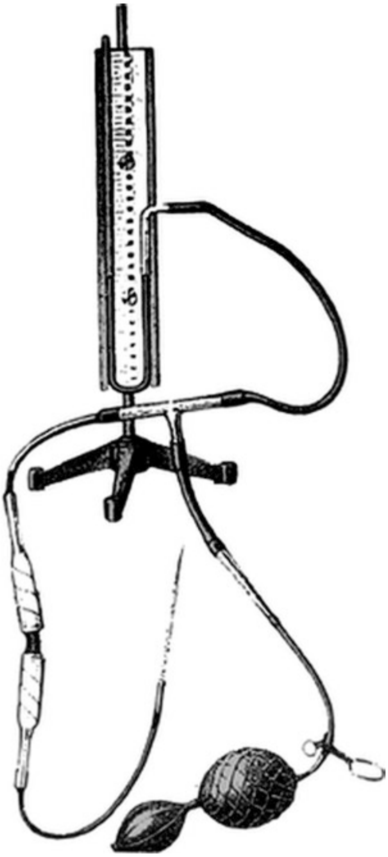

Fig. 1.3 Georg Kelling's apparatus for obtaining abdominal air insufflation

Fig. 1.4 Georg Kelling (1866–1945)

Fig. 1.5 Kurt Semm producing one of the first intraoperative video recordings

The Beginnings of Laparoscopy: The Cholecystectomy

After its initial description in the late nineteenth century, a cholecystectomy was performed through the use of a generous right upper quadrant subcostal incision. While this became the standard of care for surgical gallbladder disease, patients viewed the procedure as a painful endeavor with significant morbidity and prolonged return to normal daily activities. In the early 1980s, however, German surgeon Erich Mühe began experimenting with various methods of minimally invasive gallbladder removal based upon Kurt Semm's work, and introduced the "galloscope" in 1985. He presented his work at the German Surgical Society in 1986, but was ridiculed for what was described as "Mickey Mouse surgery". During the same time period, French surgeon Philippe Mouret successfully performed the laparoscopic approach in 1987 on a young woman 2 hour operating time using a direct-view endoscope and lying on his patient's right thigh for the majority of the case. Anecdotally, the next morning the patient was seen on morning rounds and being in such good condition on her first postoperative day, she was convinced that her gallbladder had not been removed. Two years later, Mouret and a fellow French surgeon by the name of Perissat presented the new laparoscopic procedures at SAGES. This began a revolution within the surgical community to pursue minimally invasive techniques. Within a year, laparoscopic cholecystectomy was being performed across Europe and in the United States. By 1990 there were well over 50 trade exhibits, clinics, lectures, and courses at

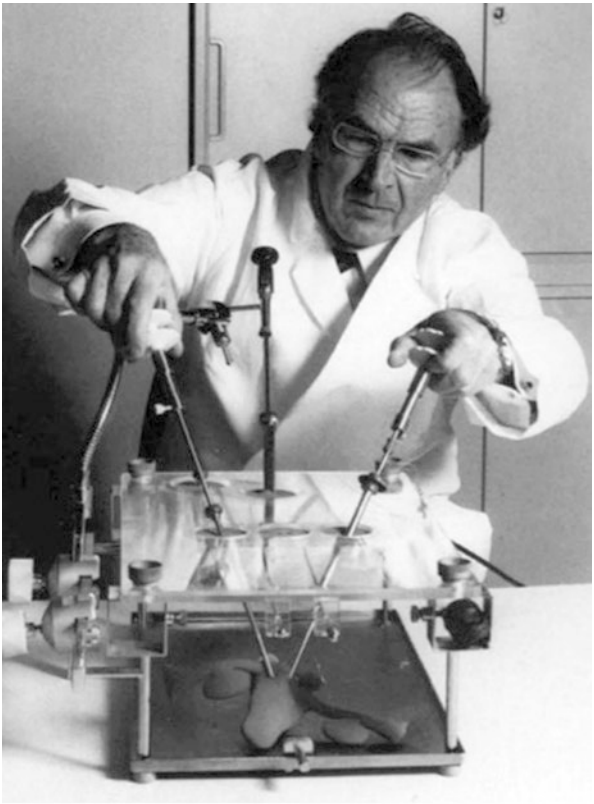

Fig. 1.6 Kurt Semm demonstrating an early version of a laparoscopic pelvic trainer for minimally invasive surgery

SAGES. In 1993, it was estimated that more than 80 % of cholecystectomies were performed laparoscopically. During this time, patient demands for minimally invasive surgeries increased while costs for laparoscopic equipment diminished due to free market competition between medical device companies. The growing demand incentivized hospitals to retrofit their operating rooms to become laparoscopy enabled in an effort to attract patients to their minimally invasive surgical practices.

Small retrospective studies and case series began documenting the increased patient satisfaction, decreased pain, and better cosmesis. Large studies mirrored these same outcomes, but also highlighted the potential drawbacks of laparoscopic operations. Within these studies, however, intolerance of pneumoperitoneum for patients with severe cardiac or pulmonary disease, increased operating difficulty in the obese, and loss of 3D viewing through a monocular video-imaging system all became sited criticisms of laparoscopy. Despite these disadvantages, surgeons began using laparoscopy for multiple indications, from diagnostic purposes to forays in resection of the larger organ systems, including the colon.

The Laparoscopic Colectomy

The removal of large organ systems such as the colon presented an interesting challenge to laparoscopic surgeons. The first series of laparoscopic colectomies was presented in 1991 and was initially used for benign disease processes such as diverticulitis and inflammatory bowel diseases; however, surgeons began performing laparoscopic colectomies for oncologic resection for malignant neoplasms. Doubts arose about the ability to perform adequate mobilization within certain regions in the abdomen (namely the pelvis), and whether laparoscopic resection could obtain appropriate margins on colon cancers, let alone perform an adequate lymphadenectomy for accurate pathological staging. Moreover, it was well known that laparoscopic surgeries suffered from loss of tactile touch discrimination and the fulcrum effect of introducing linear instruments though a trocar inserted through the abdominal wall. Criticism also focused on removal of a specimen through a small incision, which would (1) likely require large incisions approximating that of open colectomies for larger tumors, and (2) the potential for seeding laparoscopic port sites with malignant cells. By the late 1990s, however, small prospective studies focusing on laparoscopic colon resections began confirming the benefits of laparoscopy over open resections. Laparoscopic colon resections were as adequate in lymphadenectomy for staging and therapeutic purposes, had similar disease free survival as the open counterparts, and tended towards shorter hospital stays and quicker return to work.

The COST and CLASICC Trials

Prior to 2004, small studies at single-institutions or case series were prevalent in the surgical literature but were more descriptive of laparoscopic colectomies rather than supportive of their noninferiority to the current standard of care.

In response to these growing concerns from the surgical community, the Clinical Outcomes of Surgical Therapy (COST) study group conducted a prospective multi-institutional, randomized trial that ultimately showed noninferiority when comparing open versus laparoscopic colon resection. Published in 2004, the COST trial randomized 872 patients across 48 American and Canadian intuitions to undergo either open or laparoscopically assisted colectomies with the primary end point being time to recurrence. Secondary end points included intraoperative and perioperative complication rates, lengths of hospital stay, and 30-day as well as long term overall and disease free survival. The COST trial also addressed the adequacy of oncologic resection between groups as well as overall and disease free survival. The most significant conclusion from this study was a similar 3 year rate of recurrence and overall survival between laparoscopically assisted and open groups (16 % and 18 %, respectively). Additionally, surgical wound recurrence was less than 1 % in both groups and the rates of complications, 30-day mortality, readmissions, reoperations were all similar between groups while length of hospital stay and requirement for oral analgesics was less in the laparoscopic group compared to the open group.

A year later in 2005, the UK Medical Research Council (MRC) published their trial of "Conventional versus Laparoscopic-Assisted Surgery in Colorectal Cancer" (MRC CLASICC trial) in the Lancet. Unlike the COST trial, which focused on pure colon cancer, the CLASICC was notable for the addition of rectal cancers into its patient inclusion.

Similar to the COST trial, the CLASICC trial was a multicenter, randomized study of 794 patients across 27 UK centers. Endpoints included positivity rates of circumferential and longitudinal resection margins and in hospital mortality. Secondary endpoints were complication rates, quality of life comparisons at 30 days and up to 3 months, and transfusion requirements. Similar to the COST trial, there were no significant differences between laparoscopic and open groups with respect to tumor or nodal status, short-term endpoints including adequacy of resection margins, or short-term measures for quality of life. Similarly, intraoperative complications and mortality rates were not significantly different between groups. There was a higher nonsignificant trend towards positive CRMs in lower anterior resections for rectal cancers in the laparoscopic group compared to the open.

The consensus from these studies was clear: laparoscopic colon surgery was noninferior to open resection and provided a significant benefit in early postoperative recovery from pain, return of bowel function, and return to work. While there was a clear benefit in laparoscopic compared to open colon surgery, the trend towards positive CRMs for rectal cancer lead to a heated debated within the surgical community regarding the role of minimally invasive rectal surgery.

Limitations in Rectal Surgery

The struggle in identifying a definitive management stratagem has persisted throughout the history of rectal cancer surgery: from William Miles introducing the abdominoperineal resection in 1908, to the shift in sphincter-sparing surgeries with the low anterior resection by Claude Dixon in the 1940s, to the creation of coloanal anastomosis and the introduction of total mesorectal excision by Heald and Ryall. These milestones within rectal surgery are similarly mirrored by the COST and MRC CLASICC trial with regards to colon cancer surgeries, but concern for rectal cancer surgery remained. To better evaluate the oncologic safety of MIS rectal surgery, The Colon Cancer Laparoscopic or Open Resection study (COLOR II) trial was conducted, a multicenter, randomized noninferiority study comparing open with laparoscopic rectal cancer surgery. The COLOR II trial showed a reduction in the positive CRMs in the laparoscopic group compared to the open, which was largely attributed to the increased experience of the operating surgeon and improvement in laparoscopic instruments and better camera systems. Similar to the COST and MRC CLASICC trial, COLOR II demonstrated improved recovery from pain, return of bowel function, and return to work.

Expounding on this work, short-term outcome studies from the ACS NSQIP database suggest that laparoscopic-assisted proctectomies had decreased length of stay, required fewer blood transfusions, and had a lower overall 30 day mortality compared to open procedures. But, one critique of COLOR II was that fewer lower rectal cancers were done versus other large randomized studies like ALACART. The majority of rectal cancers done were middle to upper rectal cancers, instead of the more difficult lower rectal cancers. Large randomized studies like ALACART and ACOSOG Z6051 may address this group better than COLOR II. Rates of anastomotic leak and postoperative complication rate, however, remained stagnant between the COLOR II and CLASICC trials, suggesting that either this may be a manifestation of the limitation of current laparoscopic technology or a reflection of the inherent morbidity of surgical management of rectal disease. Further work is needed to assess the adequacy of MIS rectal surgery. Results from the ACOSOG-Z6051 trials to assess noninferiority from MIS compared to open rectal surgery are pending, and new technologies in MIS are continuously shaping the field.

Ultimately, a new paradigm needs to be established through which rectal cancer is managed, utilizing both earlier screening methods and evolving surgical techniques. Robotic surgery may provide a unique avenue through which colon and rectal pathology can be dealt.

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Chapter 2
The Learning Curve of Robotic Assisted Laparoscopic Colorectal Surgery and How to Start Applying Robotic Technology in Colorectal Surgery

M. Nicole Lamb and Ovunc Bardakcioglu

The mastery of the field of colorectal surgery, with its multitude of complex procedures and ever evolving modalities, begins in general surgery residency, often progresses to fellowship, and continues throughout one's career as a lifelong endeavor. Many learning curves are encountered and overcome at each stage. During the training phase the mastery of new skills is developed in a controlled environment monitored by experienced surgeons. Post-training the surgeon learns, develops, and masters new skills in an environment that is sometimes without a roadmap, yet he or she has to begin successfully implementing this skill in a safe manner for his/her patients. Although learning curves are inevitable, they also impact the subset of patients who fall under the front end of the surgeon's learning curve. During the initial learning curve, many factors contribute to the surgeon's eventual acquisition of the desired skill.

> "The learning curve is usually defined as the number of cases that a surgeon needs to perform before reaching competency for a given procedure based on comparisons with the outcomes of prior standard procedures." [1]

Factors that impact the learning curve are both surgeon and patient related. Surgeon factors can include prior experience and surgical volume while patient factors may include BMI, anatomy, and/or the complexity of surgical disease process.

Laparoscopic and robotic assisted colorectal surgeries are two of the newest surgical modalities that have risen to the forefront of the field over the last 10–20 years. Laparoscopy predates robotics and as such there is much more data on its learning curves and how these curves have been analyzed and implemented, which aids in setting the stage for later uncovering the learning curves for robotic surgery.

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In 1991 M. Jacobs performed the first laparoscopic colectomy and ever since surgeons have been trying to perfect the technique [2]. Initially and even currently one of large challenges of laparoscopic colorectal surgery has been the steep learning curve. Initially surgeons were learning this technique post-residency/post-fellowship. They were well trained and experienced in open surgical techniques with no exposure to laparoscopy so the steep learning curve was due to a complex combination of technology related factors such as learning to use straight, rigid instruments within small spaces, limited degrees of freedom, fulcrum effect, loss of tactile feedback, adapting to two-dimensional visualization, and suboptimal ergonomic design [3]. Many studies were published looking at the learning curve under these circumstances. During this time the patient enrollment in these types of studies began in the early 1990s and continued into the twenty-first century ([4–6). Based on studies from this time in surgical history, the learning curve for laparoscopy is varied ranging from 30–70 cases based on a series of single center or single surgeon experiences ([4, 5, 7]). A retrospective systematic review of the literature between 1995 and 2009 showed that the learning curve is even higher at 88–152 cases when multicenter information is included and multidimensional analysis is applied [8]. Currently, laparoscopy is an intimate part of general surgery residency and every colon and rectal surgery fellowship, which has created a surgeon different than the one cited in these types of studies. This places the learning curve of laparoscopic surgery within the confines of fellowship, and even beginning in residency, and may decrease the high number of laparoscopic cases needed to overcome the learning curve.

Many of these studies have used different methods to analyze the learning curve and have evaluated various end points; several key outcomes are consistently seen throughout all studies. The most common outcome measured can be divided into surgeon dependent factors that relate to the surgeon's ability to complete the task efficiently and are frequently measured by operative time and conversion rate ([4–6]). The other outcomes are related to patient quality and outcome factors such as length of stay, readmission rates, post-op and intra-op complication rates, and patient mortality and morbidity ([4–6]). The long learning curve associated with laparoscopic colorectal surgery and with the rise of robotic surgery, literature is arising to determine if the learning curve of robotic surgery is shorter than in laparoscopy.

The first robotic assisted colectomy was performed in 2001 and interest in applying this technology continued to grow, especially with respect to the challenges of rectal surgery [9]. The potential advantages of robotic surgery over laparoscopic have been described as its multiarticulated instruments, camera stabilization, three-dimensional magnified visualization, and ergonomic operating position [10]. There is interest to know if these potential benefits translate into a shorter learning curve as compared to laparoscopy.

Currently, all published studies of the learning curves of robotic colorectal surgery focus primarily on rectal surgery and particularly with rectal cancer but some benign disease is included. These preliminary studies suggest that the learning curve can be analyzed by evaluating a combination of time related factors: total operative time, surgeon time on the console, robot docking time, total time using the robot as well as non time related factors such as conversion rates and intra and post-operative complications ([3, 9]). It was found that the learning curve had three distinct phases:

Phase One: Initial learning curve (estimated to occur at 11–40 cases)
Phase Two: Additional experience phase—The surgeon is competent to complete the surgery and is starting to tackle more difficult cases (estimate to occur at 12–128 cases).
Phase Three: Concluding phase—The surgeon has mastery of the skill and is consistently pursuing more surgically complex operations ([3, 7, 9–12]).

It was found that as operative experience and number of cases increased, the time related factors (total operative time, docking time, console time) all decreased during phase one ([3, 9–12]). During phase two all time related factors actually increased because as the surgeon's comfort level with the robot increased as he or she began broadening the application for robotic surgery and attempting more complex surgeries and without selection bias excluding cases considered to be more technically challenging ([3, 9–12]). Interestingly, patient factors remained relatively stable across all three phases of learning.

Although these studies begin to give us an idea as to what the learning curve for robotic colorectal surgery might be there are some limitations associated with the group of studies. The currently available studies are the cumulative report of a singular surgeon at a single institution except Jiminenz-Rodriguez et al. [13] who used three surgeons in his study. Can we truly extrapolate a learning curve from a total of nine surgeons and apply it to all surgeons? Also all of the surgeons in these studies were experienced laparoscopic colorectal surgeons. Does that mean that to use the robot in colorectal surgery one needs to have extensive laparoscopic training? Some studies used a hybrid approach, performing laparoscopic splenic flexure mobilization and robotic technique for the pelvic dissection [10–12]. As robotic technology continues to advance outcomes may also alter. These studies were all performed using the daVinci S system and there have been several newer generations of the daVinci robot that have evolved with the most recent being the Xi system. All of these varying factors may contribute to the learning curve of the robot making either negatively or positively, all further investigation into this growing field will answer these questions. For now it seems feasible that robotic colorectal surgery may be an additional technique than may be developed in a shorter time frame than laparoscopy.

Adapting robotic technology to one's practice should start with a needs and purpose evaluation. Every general and colorectal surgeon's operative volume for different disease states is different based on referral patterns and own preference. This will vary from practice to practice and a first step should be a thorough review of case numbers within a time frame for all procedures in which robotic technology is currently applied, mainly robotic rectal procedures (low anterior resection, abdominoperineal resection, proctectomy, and rectopexy) and abdominal procedures (partial colectomy, Hartmann`s reversal, and total colectomy). As discussed in other chapters the patient benefit is mainly seen for rectal procedures if robotic is compared to laparoscopic surgery. But at the same time even the busiest surgeons may lack the adequate procedure number within a reasonable time frame to overcome the anticipated general learning curve.

Surgeons who adapted robotic techniques for colon and rectal surgery in the past had to compensate for the lack of adequate robotic tools for a robotic colectomy, mainly missing a bipolar vessel sealer and stapling technology. With the advent of these new instruments all benefits which are seen with robotic technology, mainly instrument articulation, improved visualization, ability to use a third arm/instrument and last but not least the introduction of the newest Xi platform can be applied to colectomies as well.

Therefore the surgeon should consider adapting robotic surgery for all indicated procedures, pelvic and abdominal. This will allow to quickly accumulating necessary experience to overcome the basic learning curve rather than loosing valuable learning points due to an increased time interval between robotic cases.

Robotic privileging is highly regulated by individual hospitals and medical staff requirements. To date no national guidelines exist to help facilitate the safe introduction of robotic surgery, but there is an increased interest of national societies to help with the process to ensure safe application and monitoring of patient outcomes.

Basic training is provided by the manufacturer as a 1-day animal lab at Intuitive Surgery facilities throughout the nation. These courses focus on the general introduction of the system and allow the surgeon to utilize and practice basic skills such as camera functions and basic instrument manipulation. Following the basic training every hospital mandates initial cases in the range of two to five to be proctored by surgeons who are certified through Intuitive Surgery in their respected specialty. The current proctor requirements are the performance of a minimum of 30 robotic procedures for which the proctor is certified within the preceding 12 months.

A next crucial step after the initially proctored cases is to adapt accepted and standardized guidelines for procedures rather than “reinventing the wheel”. These are available through various sources including guides published by Intuitive Surgical, textbooks, and experienced colleagues. In this initial phase one of the learning curve as described above, the surgeon should consider selecting patients with more favorable characteristics such as a low BMI or no prior abdomino/pelvic surgery. Additionally, the surgeon should start introducing the robotic technology slowly and completing some of the procedure with a more familiar laparoscopic approach. This could for example mean only mobilizing the colon robotically and dividing the central vessels laparoscopically, performing an extracorporeal rather than an intracorporeal anastomosis for a right hemicolectomy or performing the TME dissection robotically only and using laparoscopy for the abdominal portion of a low anterior resection. This will allow safe and efficient introduction of robotics without frustration to the surgeon and safe outcomes.

After the surgeon is comfortable with the basic operations and initial procedure experiences of phase one at 11–40 cases, it is recommendable to attend a specialized multi day training course in robotic colon and rectal surgery available through the manufacturer or national societies. This could be supplemented with additional proctoring on the advanced level throughout phase two of the learning curve.

To summarize, application of robotic technologies in colon and rectal surgery has many benefits for the patient, but a thoughtful and well organized introduction and evolution within ones learning curve is a crucial element for success.

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Chapter 3
Training and Credentialing in Robotics

Ryan Broderick, Simone Langness, and Sonia Ramamoorthy

Background

Since the introduction of robotics in minimally invasive surgery in the 1990s, many new devices and advances in technique have been developed. In addition, access and exposure have been increasing, with currently more than 3266 da Vinci Surgical Systems (dVSS, Intuitive Surgical, Sunnyvale, CA) in hospitals worldwide accounting for 570,000 procedures in 2014 [1]. Overall, the use of robotics in minimally invasive surgery has reportedly produced significant improvement in many aspects of surgery, including decreased postoperative pain, decreased physiologic insult, faster recovery times, and improved cosmesis [2–4]. Compared to laparoscopic surgery, robotic surgery provides better visualization and dexterity in many situations. Patient demand, physician demand, and industry involvement have driven the advancement of both laparoscopic and robotic surgery. The trend toward minimally invasive techniques in general, and robotics in particular, has significantly altered the focus and characteristics of surgical training programs. Open surgical training, and the Fundamentals of Laparoscopic Surgery (FLS) curriculum, is now required by governing bodies such as the Accreditation Council for Graduate Medical Education (ACGME) to obtain board certification and has been vetted as safe and effective surgical training [5–13]. With the rapid expansion of robotics in general surgery and surgical subspecialties, the education and certification materials are not as well developed nor as well regulated as earlier surgical techniques (e.g., laparoscopic surgery). Similar to laparoscopic surgery training, the future of robotic surgery training should feature objective metrics in a curriculum that can be broadly applied across training institutions and also allow for specific subspecialty training.

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Current Credentialing and Privileges in Robotics

Credentialing by a certifying organization verifies that a surgeon meets objective standards for performance of clinical tasks or operations. Privileging is defined as the surgeon's scope of practice based on performed competency. Despite having multiple master-slave robotic platforms in the past such as the Automated Endoscopic System for Optimal Positioning (AESOP; Computer Motion, Santa Barbara, CA), the Zeus Surgical System (Computer Motion), and the da Vinci Surgical System (dVSS), the only FDA-approved platform at this time is the da Vinci Surgical System. A steep learning curve is a well-documented hurdle in the early stages of surgical training in general as well as adoption of new surgical techniques, and robotic surgery training (specifically with the dVSS) is not an exception [14]. Training programs with the dVSS have been initiated in an attempt to decrease the risks for patients during initial attempts at robotic surgery and to assist in the credentialing process.

Current training for the dVSS consists of an introductory industry-sponsored training program. The training features 8 h of training on an animal (porcine) model as well as virtual reality (VR) simulator. Following the initial introductory course, far less regulation exists regarding specialty-specific training. Many hospitals have further opportunities for observation, and feedback is available through proctors; this however can be accompanied by costs to the participant or hospital if a suitable proctor is not readily available locally. Specialty-specific training appears to offer participants the most utility for robotic practice preparation. These courses are designed to give the new robotic surgeons tips and tricks that include efficiency with setup and OR team operations, avoiding common errors in patient selection and avoiding complications, and utilization of proper instrumentation [15].

Because training practices for the credentialing process are provided through the industry that provides and sells the systems, objective measures to ensure safety and proficiency cannot be guaranteed [16–18]. There is little data to show construct validity of the dVSS courses [15, 19, 20]. The device industry nevertheless is motivated by both market forces and FDA pressure to ensure safe and responsible utilization of their systems. In the case of robotics, the technology is evolving and rapid progress is being made not only in area of device development but in the development of training tools such as virtual simulation. Few can argue with that fact that this investment will have a lasting impact on surgical education for the future.

Robotic Training Development and Research

Significant challenges must be addressed to develop a standardized robotic surgery curriculum. First, the cost of robotic surgery is much higher than for most laparoscopic devices attributed to the initial purchase start-up cost and service contract, with significant time and expense dedicated to maintenance. Due to the high cost, a dVSS is more profitable when used for patient care than for training time and therefore may limit trainees' access when systems are operational. Similar challenges were faced during the introduction of laparoscopic surgery, but it has been established by the Fundamentals of Laparoscopic Surgery (FLS) that inanimate objects can be as a significant part of training, which improves cost-effectiveness [5–13].

Research has been initiated to develop more cost-effective, inanimate, and virtual reality training for robotic surgery [15, 18–33]. Using the validated FLS objective metrics, inanimate training in robotics consists of peg transfer, camera movements, and suturing techniques in addition to other defined skills specific to robotic surgery. Many groups have also begun validating their own inanimate and virtual reality systems for robotic training [31–33]. Both content and face validity have been proven with inanimate trainers [18, 21, 29–33]. Despite these results, a remaining hurdle for training, even with inanimate objects, is that the robot must be available and not in use for patient care. An additional hurdle is that the inanimate training modules have been criticized for not providing adequate anatomic representation, resulting in limited feedback on the intraoperative consequences for various actions, although research on cross method validity is beginning to take shape [32].

Virtual reality (VR)-based simulators have been pursued as the ideal model for robotic training. Available simulators in practice currently include: the Mimic dV-Trainer (MdVT) (Mimic Technologies, Seattle, WA), the da Vinci Skills Simulator (Intuitive Surgical, Sunnyvale, CA), the Robotic Surgical Simulator (RoSS) (Simulated Surgical Systems, Williamsville, NY), the SEP Robot (SimSurgery, Oslo, Norway), and novel platforms for specific procedure training [33]. The goal of VR training is to provide realistic practice in a controlled setting without exposing patients to risk. As training exercises, VR simulators have been able to construct programs for specific operations and skills.

VR simulators are valuable training tools, especially for novice robotic training, with varying content and construct validity [19, 30, 32, 33]. Each system has degrees of face, content, and construct validity for their various analyzed skills but with limited procedure-based components of training [30]. Comparative studies of the available simulators have not been performed to provide information on which system may be most effective. Additionally, comparisons between VR-based training and animal labs are in early phases to determine if VR may replace or should be used in conjunction with animal and/or inanimate models or initial operations during the training phase [32].

Two newer areas for VR training are procedure-based modules with relevant anatomy and escalating complexity to engage the user. These procedure-based modules are currently under development for the robotic platform and may be incorporated into future VR trainers in the future.

The physical separation between operator and instructor required by the dVSS master-slave configuration decreases the ability of the instructing surgeon to teach safe and effective surgical techniques. Dual-console robots have been developed by dVSS with some subjective improvement in training and a more controlled environment for trainee and experienced robotic surgeons. An improvement in training with the dual console has not yet been confirmed with data, and the cost for obtaining and using dual-console robots is prohibitive for many health-care systems [29, 34]. Nevertheless, the dual console appears to facilitate robotic teaching as it makes use of the "drivers education" model with a "brake" for the trainers to take over if needed, thereby giving the trainer added security when handing over the console.

Research efforts from multiple groups in both VR-based and inanimate techniques have provided valuable information but have reported conflicting, competing, and redundant training and assessment tools [21, 24–26, 29–33]. Also, in addition to the technical skill set that must meet a minimum proficiency in all realms of surgery, including robotics, communication, teamwork, decision making, and judgment should be verified prior to the independent use of a robotic surgical system [21, 22]. Inanimate training, VR simulation, and proctored operations each have strengths and limitations as isolated training tools. Each of these methods can play a significant role in robotic training, credentialing, and privileging in the future [30–33].

Fundamentals of Robotic Surgery (FRS)

Robotic and computer-based surgery will increase in the operating room as the technology expands. New platforms and methods will be developed in the future, including single site, bio-inspired designs and multiple computer-based operating systems. With the upcoming innovation in robotic surgery, surgical leaders and accrediting bodies require a standardized, objective curriculum that may be used across all robotic and computer-based platforms for credentialing. The system should be applicable across all surgical specialties, encompassing between-specialty and within-specialty validation [23]. The Fundamentals of Robotic Surgery (FRS) has established a base curriculum for robotic surgery training, and large government-sponsored grants provide funding for data collection with adequate scope and large enough case numbers to meet the strict requirements of certifying bodies [14, 16].

The goal of the FRS curriculum is to be implemented by training programs and accrediting bodies in ways similar to the FLS curriculum. FRS curriculum development is based on mechanical training in the form of specific, objectively evaluated tasks (technical skill, camera movement, team work, etc.) [35]. Established educational principles will also be applied to ensure a curriculum which trains competent and safe surgeons. While recent studies have validated curricula at individual centers [33, 34, 36, 37], validation of the FRS curriculum will be performed by a series of randomized trials. The data acquired from the randomized trials will be presented to national and specialty certifying bodies with the hope that the FRS curriculum will become a required component of surgical training and certification [16, 17, 24, 35].

The access to robotic surgery is quickly expanding, and with that expansion is a growing number of procedures that will benefit from a robotic surgery environment. Safe and effective surgical operations are of the utmost importance to patients. A single, certified training curriculum that prioritizes patient safety can ameliorate the unique challenges in robotic surgery training. The ideal basic curriculum will be applicable across specialties and adaptable to future changes, platforms, and technologies within robotic surgery [35]. The curriculum will then be a springboard to provide further certification in surgical subspecialties. A validated Fundamentals of Robotic Surgery (FRS) will be required training prior to the independent use of robotics in the operating room.

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Chapter 4
Robotic Right Hemicolectomy

Henry J. Lujan, Brian X. Rivera, and Diego Holguin

Background

The first robotic colectomies were reported by Weber et al. in 2002 and included one right colectomy [1]. Since then, the da Vinci® surgical robot (Intuitive Surgical, Sunnyvale, CA) has been shown to be safe and effective for colorectal procedures by other authors [2]. Nevertheless, the role of robotic right colectomy continues to be debated and a clear consensus has not been reached. DeSouza et al. in their review concluded that it might best be used as a surgeon's initial experience and as a teaching tool [3]. More recently, Park et al. did not find an advantage over conventional laparoscopy and could not recommend its use [4]. However, they did acknowledge that the technology and instrumentation is evolving rapidly and this would have to be reevaluated in the future.

Laparoscopic colectomy has been shown to have significant advantages over open colectomy [5]. Laparoscopic colectomy is even considered the gold standard by some authors [6, 7]. Robotic colorectal surgery today may be in the same position that laparoscopic surgery was 25 years ago [8, 9]. Despite first being described by Jacobs et al. in 1991, laparoscopic colectomy has been slow to be adopted as the preferred approach to colon and rectal diseases. Estimates for the

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percentage of laparoscopic colectomies performed in the USA range from 40 to 45 % and for laparoscopic rectal resection range from 10 to 15 % [10, 11].

Initially, laparoscopic colectomy took longer and was more expensive than conventional open colectomy. However, with time, it proved to offer significant advantages to the patient, including quicker return of bowel function, less post operative pain, shorter hospital stay, and lower postoperative morbidity and mortality [5]. Robotic surgery purportedly offers advantages to overcome the limitations of laparoscopic surgery [2]. Some surgeons believe this could lead to wider use of minimally invasive surgery techniques for colorectal resections [12].

Robotics for colorectal surgery has been shown to be safe and feasible, and perioperative and pathologic outcomes appear to be equivalent to laparoscopic surgery. However, most authors believe that the robot will have the greatest impact on rectal resection [2, 12]. It seems ideally suited for pelvic dissection, where the superior visualization and articulating instruments facilitate exposure, retraction, and difficult dissection. It is hypothesized that these advantages will result in lower conversion rates and higher rates of adoption. Furthermore, possible advantages of better mesorectal excision, better preservation of nerves, and easier operation in the obese are all areas of ongoing investigation. But, for partial colectomy, the benefits are more difficult to foresee. In the literature, modest advantages in visualization and possibly decreased blood loss seem to be offset by longer operative times and higher costs thus far [4, 13].

If nothing else, robotic right colectomy is an ideal case for a surgeon's initial experience with robotic techniques [3]. It is a familiar procedure to general and colorectal surgeons alike. It is technically easier than other colon procedures with relatively short operative times. It is commonly used as learning and/or teaching tool. It is a procedure that is easily converted to either laparoscopic or open colectomy with relatively little clinical consequence.

The indications and setting for right colectomy are well described and include benign and malignant conditions, elective, urgent, and emergent operations. Benign conditions include: inflammatory bowel disease, volvulus, diverticular disease, arteriovenous malformations, ischemic colitis, and polyps not amenable to endoscopic removal. Adenocarcinoma, carcinoid tumor, and appendiceal tumors account for most malignant diseases. Surgery for the right colon is usually elective. However, urgent indications include nearly obstructing lesions, ischemic colitis, and hemorrhage. There are only a few emergent indications, with perforation, complete obstruction, and refractory hemorrhage the most common [14].

Technique

1. Room setup and patient positioning

Our three-arm technique for robotic right colectomy with intracorporeal anastomosis has been previously described [15]. We modified this technique from the description by Crawford et al. [8]. The patient is under general anesthesia in the supine position. Room setup is shown in Fig. 4.1. Pneumoperitoneum can be

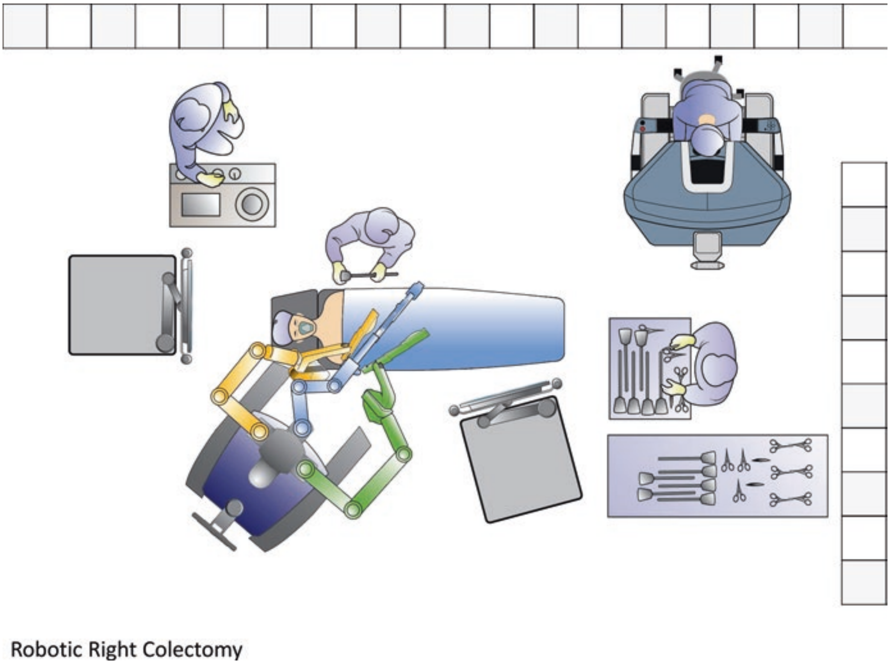


Fig. 4.1 Room setup

achieved with a Veress needle. As an alternative, open laparoscopic entry (Hasson technique) or visual entry systems (Optiview/Visiport) can be used per surgeon's preference. Patient positioning is performed just prior to docking the robot. The table is positioned in 10–20° of reverse Trendelenburg and 15–30° of right side up to allow the small intestine to fall away from the midline (Fig. 4.2a–c).

Some authors prefer 10–15° of Trendelenburg so that the terminal ileum is better exposed for dissection of the pelvic brim. This is an important point that is best addressed at the time of initial evaluation by laparoscopy. If the terminal ileum is fixed in the right lower quadrant, it may be difficult to free the bowel in a fixed table position with the patient in Trendelenburg. We recommend early evaluation in order to be able to complete this portion of the operation with the robot. Alternatively, the terminal ileum can be freed laparoscopically. Occasionally, it may be necessary to undock the robot in order to change the table position so that lysis of adhesions can be completed by either laparoscopic or robotic means.

Localization of the pathology is mandatory during the initial laparoscopic evaluation. Our preference is to have the lesion tattooed preoperatively. Therefore, for most right colectomies, the patient is supine and access to the perineum is not necessary. In select cases, the lithotomy position may be advantageous. For example, if intraoperative colonoscopy is necessary to check the anastomosis or confirm adequate removal of the pathology, access to the perineum is needed. Lithotomy position is preferred when transrectal or transvaginal extraction of the specimen will be performed. Finally, when the possibility of avoiding a resection exists, as in

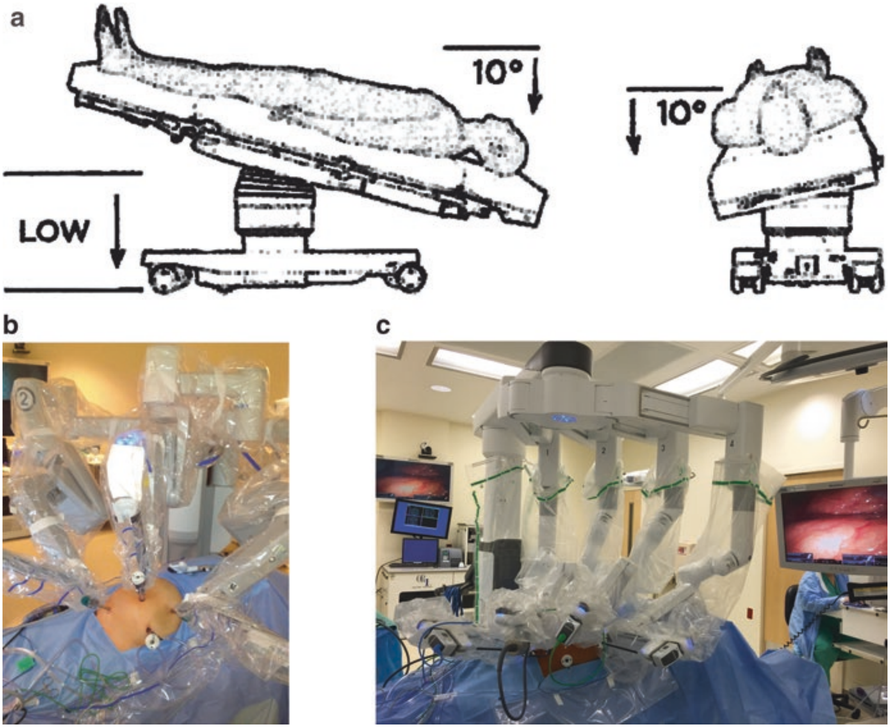


Fig. 4.2 (**a**) Table position. (**b**) Si picture robot docked. (**c**) Xi picture robot docked

colotomy and polypectomy, laparoscopic-guided polypectomy, or wedge resection of a benign lesion, the lithotomy position is used.

2. Port placement

The port placement for Si and Xi systems differ and diagrams are shown for the different configurations (Figs. 4.3, 4.4, and 4.5). Our preferred port placement for a three-arm Si system technique is shown in Fig. 4.3a. It is specific for cases when the EndoWrist® Stapler 45 System (Intuitive Surgical, Inc., Sunnyvale, CA) is not available. When the EndoWrist® Stapler 45 System is available for use, we replace the left upper quadrant 8 mm port with the 13 mm stapler port. In this case, the assistant 12 mm port can be downsized to a 5 mm port as shown in Fig. 4.4a and b. Some authors prefer a four-arm Si technique and the common port configurations are shown in Fig. 4.5a and b.

Si Port Placement

An extra long 12 or 8.5 mm periumbilical port for the camera is placed, usually 2 cm below and 2 cm lateral to the umbilicus (depending on the patient's body habitus). A left upper quadrant and suprapubic 8 mm robotic trochars are placed for arms 1 (R1)

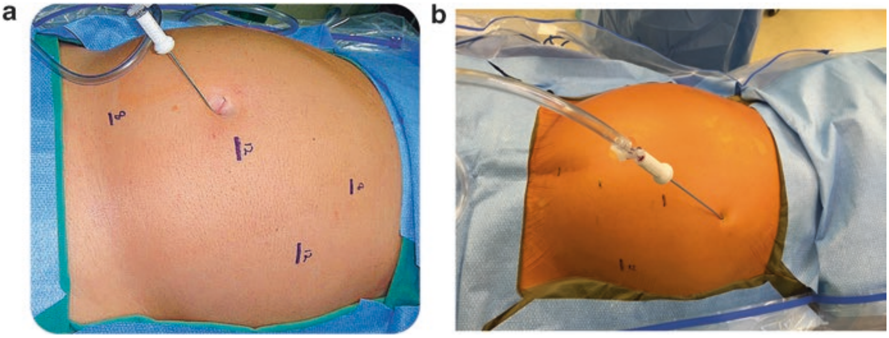


Fig. 4.3 (**a**) Si ports three arm. (**b**) Si Veress. (**c**) Xi Veress

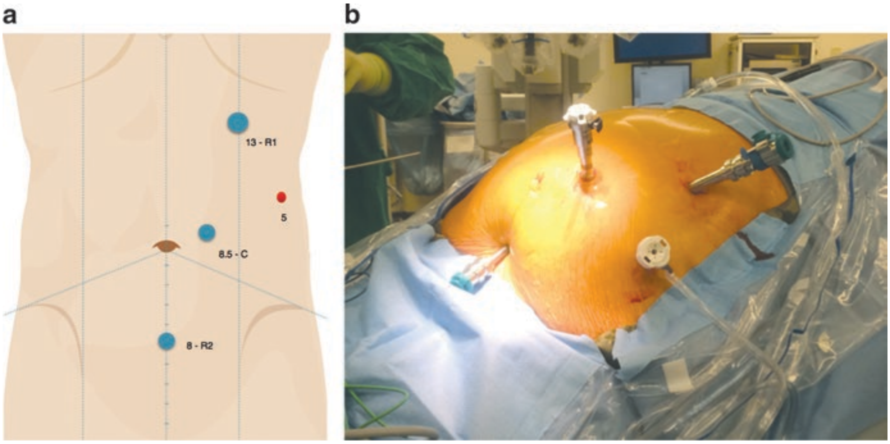


Fig. 4.4 (**a**) Si ports. (**b**) Si picture ports

and 2 (R2). Five mm robotic trochars and arms can be used, but this limits the instrument options and degrees of articulation with today's available instrumentation, and, therefore, we prefer 8 mm ports at this time. In cases of polyps or tumors, the lesion is localized prior to docking the robot using a 5 mm laparoscope, which is always available. The table is then positioned in 10–20° of reverse Trendelenburg and 20–30° of right side up to allow the small intestine to fall away from the midline. The robot is docked from the patient's right side or over the right shoulder. Although this chapter describes a three-arm technique below, a fourth arm can be added intraoperatively if needed. An additional port (R3) can be added to the right lower quadrant or the subxiphoid area (see Fig. 4.5a and b). In select cases, particularly in the obese patient, it may be advantageous to start with a four-arm technique to facilitate the procedure.

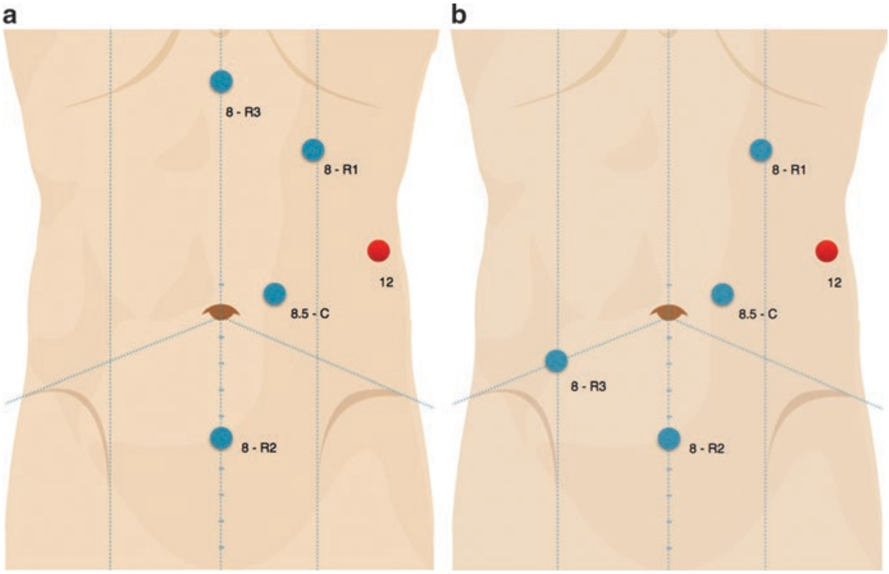


Fig. 4.5 (**a**) Si ports four arm. (**b**) Si ports four arm

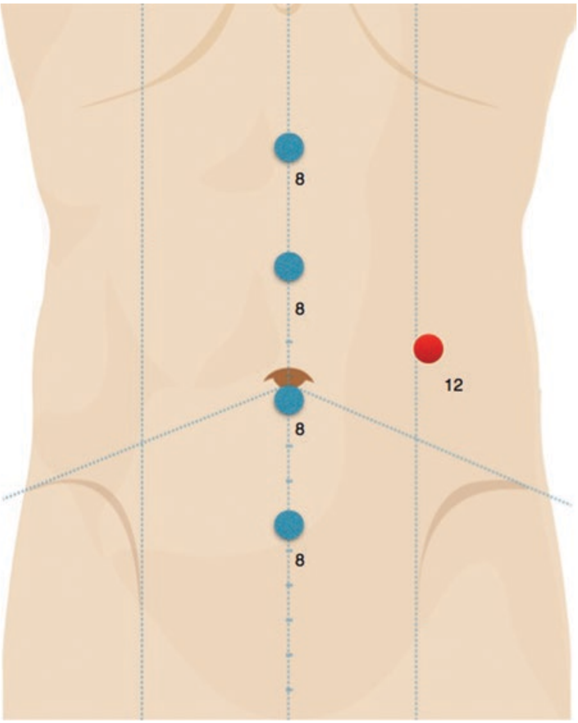
Xi Port Placement

There are two port placement options that can be utilized with the Xi system depending on whether extracorporeal or intracorporeal anastomosis is performed. The port placement guidelines as published by Intuitive Surgical, Inc. for the da Vinci Xi is shown in Fig. 4.6. This is ideal for extracorporeal anastomosis. With this port configuration, any port site (typically the umbilical trochar site) can be extended and utilized as an extraction site. Incorporating trochar sites has cosmetic advantages.

For intracorporeal anastomosis, we recommend a modification as shown in Figs. 4.7 and 4.8. This diagonal orientation extends from a port placed midline and 4–6 cm above the pubis. The diagonal now proceeds to the splenic flexure at 6–8 cm intervals. The fourth port is the 13 mm stapler port. As will be shown, this port can later be used as the extraction site if cosmesis is not important. An assistant 5 mm port can be placed equidistant from ports 3 and 4 or 2 and 3 depending on the patient's body habitus. For situations where the robotic EndoWrist® Stapler 45 System is not available, only four 8 mm robotic ports and a 12 mm assistant port are used as shown in Fig. 4.8. In this case, a 12 mm assistant port is necessary for bowel transection and creation of the intracorporeal anastomosis utilizing standard endoscopic staplers.

With the Xi system, the port configurations when placed in a line allow the most consistent performance of the entire operation [16]. The line should extend from 4 cm above the pubis in the midline toward the splenic flexure with ports placed

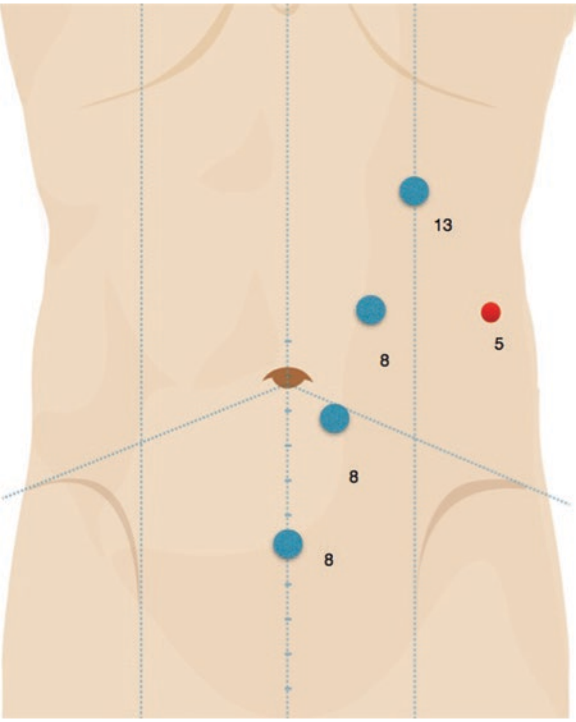
Fig. 4.6 Xi ports midline



6–10 cm apart (see Fig. 4.7). Slight angulation away from the hepatic flexure provides in-line viewing of and access to a greater length of the proximal transverse colon. Further, moving the line of ports off the midline to the patient's left facilitates dissection of the ileocolic pedicle. For complete mesocolic excision with central vessel ligation moving the entire line of ports further toward the patient's left will enable access to the middle colic vessels along with more length of the transverse colon. Midline ports (placed along the linea alba) would lie directly above the ileocolic origin and might make its dissection more challenging. The assistant port is placed in the left lateral mid-abdomen.

Since the robotic EndoWrist® Stapler 45 System was not yet available for the Xi at the time of this publication, it is recommended to add a 12 mm assistant port in the left lateral mid-abdomen for an intracorporeal anastomosis with a laparoscopic stapler. For an extracorporeal anastomosis, the port placement line can be through the umbilicus and linea alba (Fig. 4.6) with the port for arm 2 being placed at the umbilicus (which can be extended later for bowel exteriorization/specimen extraction). When the robotic stapler is available, a 13 mm port for arm 4 placed in the left upper abdomen is needed for the insertion of the robotic EndoWrist® stapler for intracorporeal anastomosis creation.

Fig. 4.7 Xi ports diagonal



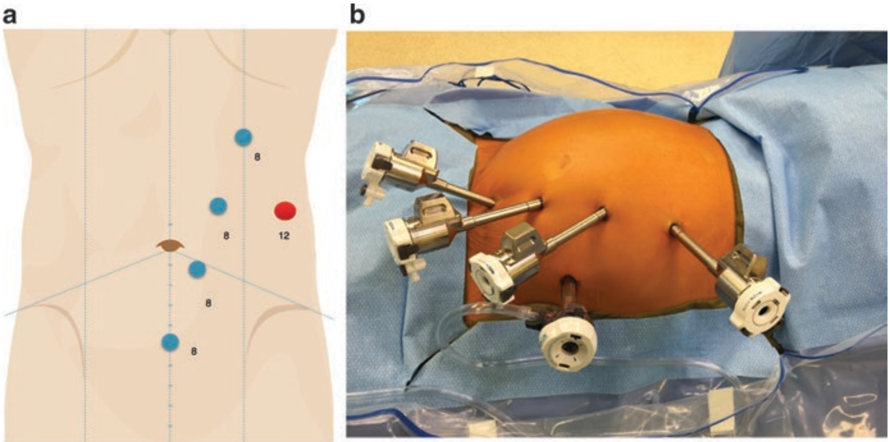


Fig. 4.8 (**a**) Xi ports diagonal. (**b**) Xi picture ports

Xi instrumentation for robotic right colectomy includes EndoWrist® Stapler 45 System, EndoWrist® One™ Vessel Sealer, bipolar fenestrated grasper, Tip-Up fenestrated grasper, and needle drivers. With regard to instrumentation, we recommend the use of the fenestrated bipolar in arm 1; 30° down da Vinci endoscope in

Table 4.1 A summary of the critical steps of robotic right colectomy with intracorporeal anastomosis (ICA) using a medial-to-lateral (MtL) dissection and preferred instruments

	Instruments
1. Identification of ileocecal junction (IJ)	HS, BF, TUp
2. Traction on IJ to expose the ileocolic vessels at their origin	HS, BF, TUp
3. Identify duodenum	HS, BF, TUp
4. Transect ileocolic vessels at their origin	HS, BF, TUp
5. Medial-to-lateral dissection	VS, BF, TUp
6. Transect terminal ileum	EW-S, BF, TUp
7. Mobilize hepatic flexure (identify MtL dissection plane)	VS, BF, TUp
8. Identify and divide right colic and right branch of middle colic	VS, BF, TUp
9. Isolate and transect transverse colon	EW-S, BF, TUp
10. Intracorporeal, side-to-side, isoperistaltic anastomosis	EW-S, ND
11. Detach specimen, complete lateral dissection if needed	HS, BF, TUp
12. Specimen extraction (wound protector)	Alexis™

HS hot shears, *BF* bipolar fenestrated grasper, *TUp* Tip-Up grasper, *VS* EndoWrist® One™ Vessel Sealer, *EW-S* EndoWrist® Stapler 45 System, *ND* needle driver. Alexis™ wound retractor (Applied Medical, Rancho Santa Margarita, CA)

arm 2; Monopolar Scissors (hot shears), Permanent Cautery Hook, or EndoWrist® One™ Vessel Sealer device in arm 3; and a Tip-Up fenestrated grasper or Small Graptor in arm 4 (see Table 4.1). The Xi has to a great extent eliminated issues with arm collisions. So, although we advocate a three-arm technique with the Si system, we have adapted our technique to include all four arms with Xi.

3. Technique/procedure

The robotic camera is inserted through the 8.5 mm periumbilical port. The assistant surgeon uses a lateral 12 mm port to introduce laparoscopic instruments, energy devices, endoscopic staplers, and suction as needed. Using the bipolar fenestrated grasper (R2) and the hot shears (R1), a medial-to-lateral (MtL) dissection is realized. The port placement is as shown in Fig. 4.3. First, the assistant surgeon grasps the ileocecal junction (IJ) to place the ileocolic vascular pedicle on tension. It is critical to identify the cecum and ileocecal junction; this step cannot be over emphasized (Fig. 4.9a). A small window is created posteriorly near the origin of the ileocolic vessels. The dissection is continued for 2–3 cm to reveal the duodenum (Fig. 4.9b). Typically, the duodenum identifies the origin of the ileocolic artery. A second window is created to isolate the base of the vascular pedicle. It is divided at the level of the duodenum with a vascular stapler load on the endoscopic stapler, clips, or energy device, which are brought in through the left lateral 12 mm assistant port or the EndoWrist® One™ Vessel Sealer may be used.

The medial-to-lateral dissection is continued. The right mesocolon is mobilized off the retroperitoneum. This dissection is mostly blunt and accomplished by pushing the mesocolon anteriorly and the retroperitoneum posteriorly. This can be advanced to the lateral attachments, to the liver and hepatic attachments, and to the

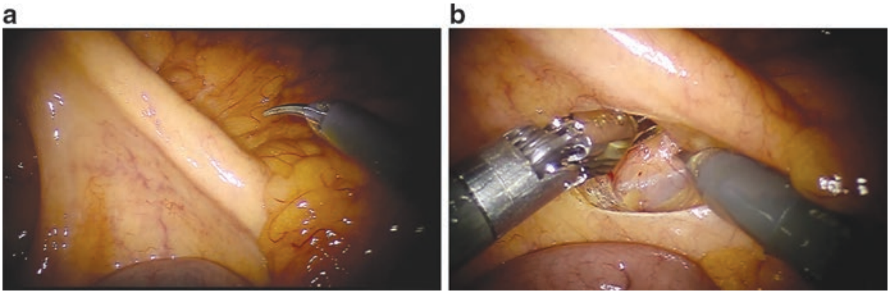


Fig. 4.9 (**a**) Picture IC vessels. (**b**) Picture duodenum

duodenal sweep as needed. The ileal mesentery is divided with an energy source or cautery to a point 8–10 cm from the ileocecal valve. Typically, two small vessels or branches will be encountered and can be divided with an energy device or EndoWrist® One™ Vessel Sealer. The mesocolic mobilization is then carried up to the duodenum and the transverse mesocolon. The terminal ileum is transected with an endoscopic stapler or EndoWrist® Stapler 45 System. Next the right branch of the middle colic is identified and transected with the energy device or stapler. The ascending colon can be left attached to the right paracolic gutter to keep it from falling medially or completely detached and the specimen placed above the liver for later retrieval (if the resection is for cancer, the specimen is placed in a bag). Lateral mobilization begins at the ileocecal junction along the right paracolic gutter and advanced to the hepatic flexure and along the right transverse colon. Sometimes omentum is removed with the specimen. Usually, the omentum is partially detached from the colon by dividing the gastrocolic ligament. The transverse colon is isolated by creating a mesenteric window and then divided with the endoscopic stapler or EndoWrist® Stapler 45 System.

Next, attention is turned to construction of an isoperistaltic, side-to-side ileocolic anastomosis. For this purpose, the terminal ileum and the transverse colon stump are brought together side by side as shown in Fig. 4.10. A 20 cm nonabsorbable suture on a Keith needle is used to put a stay suture approximating the transverse colon and terminal ileum up to the abdominal wall to provide tension and elevate the site of the anastomosis. Prior to creating the enterotomies, an endoscopic intestinal clamp (bulldog) can be placed on the terminal ileum to prevent spillage (not the author's routine). Using an energy device or hot shears (author's preference), a colotomy and ileotomy are created through which the jaws of the endoscopic linear stapler or EndoWrist® Stapler 45 System are introduced to construct the common channel (Figs. 4.11 and 4.12). The remaining common enterotomy is then closed with 2-0 vicryl in two running layers using robotic suturing techniques (Fig. 4.13).

Once complete, the stay suture is cut and then attention is directed again to the specimen. As an alternative, a complete robotic sewn anastomosis can be fashioned. If necessary, the remaining lateral and hepatic attachments are freed. A grasper with teeth or endoloop is introduced through the 12 mm left lateral port to hold the speci-

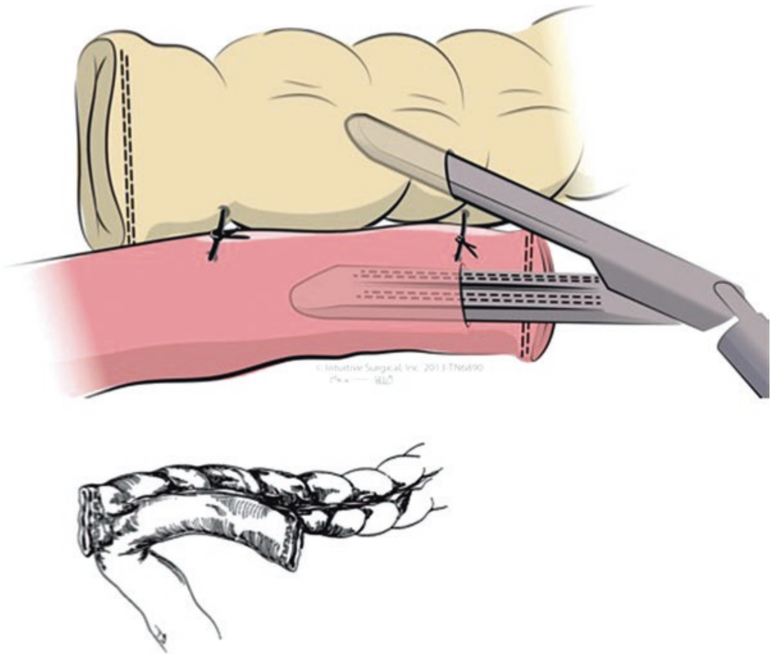


Fig. 4.10 Iso ICA

Fig. 4.11 Picture stapler 45

Fig. 4.12 Picture stapler 45

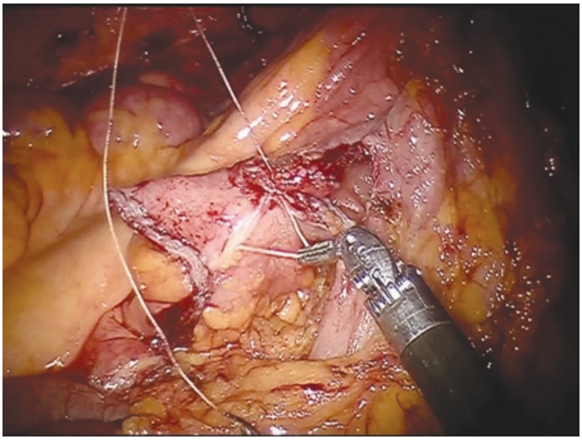


Fig. 4.13 Picture suture enterotomy

men (usually by the transected terminal ileum) and the robot is undocked. The 12 mm assistant port incision is then enlarged. We like to use the largest port incision for the extraction site since it will require closure anyway. Typically, only a 3–5 cm incision is necessary depending on the size of the pathology. A wound retractor (Alexis™ wound retractor, Applied Medical, Rancho Santa Margarita, CA) is placed to protect the skin, and the specimen is extracted. The extraction incision site can be placed in the suprapubic region or at any site per surgeon's choice as shown in Fig. 4.14. Specimen extraction is typically transabdominal. As mentioned, intracorporeal anastomosis allows the surgeon to choose the extraction site as shown in Fig. 4.15.

Finally, laparoscopy can be performed to visualize the anastomosis and confirm hemostasis. It is not necessary to close the mesentery defect in most cases (the authors do not close the defect). The extraction site is closed in two layers. Any 12 mm port site incisions are closed. The skin is closed in subcuticular fashion

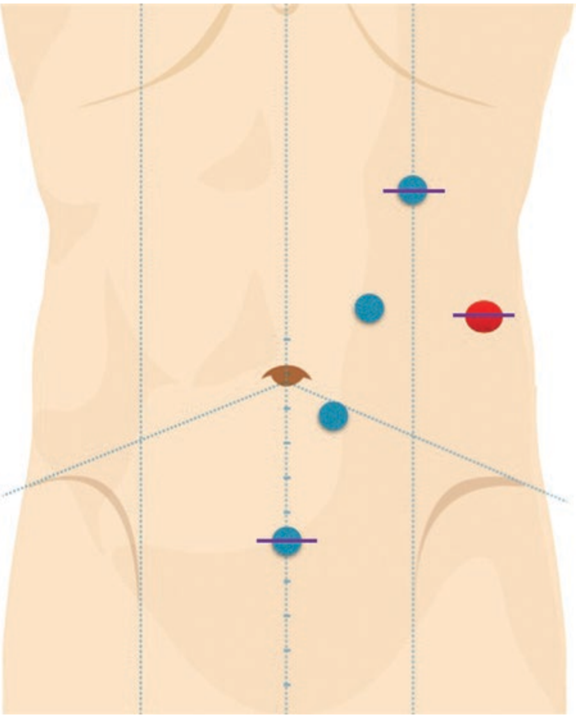


Fig. 4.14 Extraction sites

(Fig. 4.16). A summary of the critical steps of robotic right colectomy with intracorporeal anastomosis (ICA) and our preferred instruments is shown in Table 4.1.

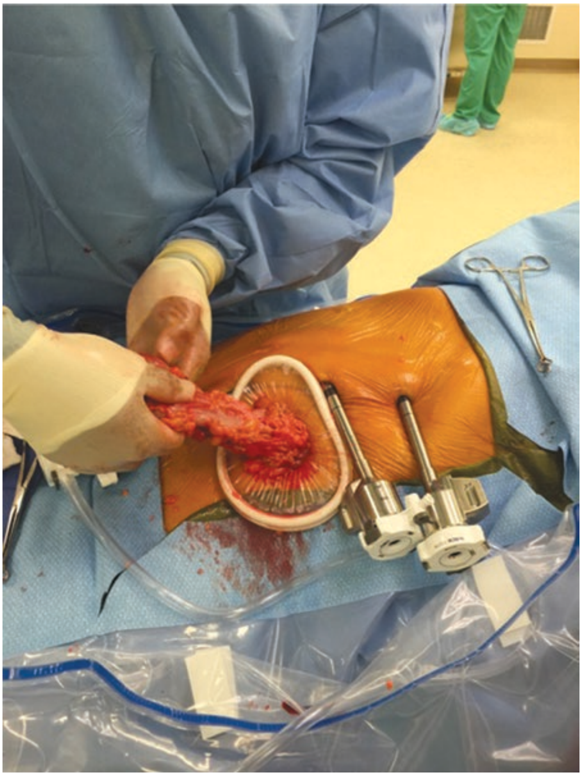
Personal Experience and Outcomes

In 2011, our initial series was published comparing 25 laparoscopic to 22 robotic right colectomies [17]. Outcomes were similar and no conversions to open were necessary. Operative times were longer in the robotic group; however, intracorporeal anastomosis was used in the robotic group, whereas an extracorporeal technique was used in the laparoscopic group. We used a three-arm robotic colectomy technique from the start of our learning curve, initially to simplify the setup and decrease arm collisions.

By only utilizing three robotic arms when using the Si system, port placement is easier because there is less concern with arm collisions. This is especially useful during the initial experience when the surgeon is challenged with multiple nuances of a new technique. As experience is gained, a fourth arm can be used selectively. We have found it advantageous to use the fourth robotic arm in right colectomies in the obese patient and when the dissection is challenging.

We believe the technique as we described above can be used in most cases and decreases time-consuming exchanges of instruments to the robotic arms. A 12 mm

Fig. 4.15 Picture extraction



left lateral port allows the assistant to quickly do the necessary exchanges of graspers, suction, harmonic scalpel, suture transfer, and laparoscopic staplers. The assistant is kept actively involved in the procedure and robotic arm exchanges are minimized. This is also useful when the assistant is teaching the procedure to the console surgeon. It may also make the operation more efficient.

More recently, our outcomes with 52 robotic right colectomies were published [18]. We have updated the demographics, outcomes, and complications for 100 robotic right colectomies for this chapter and summarized them in Tables 4.2 and 4.3.

Discussion

The first robotic right colectomies described were hybrid; in other words, an extracorporeal anastomosis was utilized. When we perform a robotic-assisted right colectomy with an extracorporeal anastomosis, the mobilization, devascularization, and transection are performed under robotic guidance. The specimen is brought out through an extraction site and the anastomosis is realized through this same wound. We found it useful to perform right colectomies in hybrid fashion early in our learning curve. Specifically, our first six right colectomy cases were performed in this

Fig. 4.16 Picture cosmesis

fashion emulating our laparoscopic technique. However, inspired by the robotic platform, we have since performed 91 robotic colectomies with intracorporeal anastomosis (Table 4.2). We also performed extracorporeal anastomosis in the two cases that were converted to open and in one case in which mobilization of the terminal ileum was exceedingly difficult and required a more extensive resection of the terminal ileum, for a total of nine extracorporeal anastomosis out of 100 robotic right colectomies.

In their systematic review of the literature, Antoniou et al. identified 39 series, which reported a total of 210 robotic right colectomies [12]. The mean operative time for these cases was 167 min (range 152–228). These series included right colectomies with both extracorporeal and intracorporeal anastomotic techniques. Conversion rate was very low, 1.1 % to laparoscopic and 1.1 % to open. Intraoperative complications occurred in one patient (0.7 %). Overall postoperative morbidity was 12.7 %.

In a recent meta-analysis comparing robotic to laparoscopic right colectomy, Xu et al. analyzed seven studies, which included 234 RRC and 415 conventional LRC [13]. The authors concluded that robotic right colectomy has longer operative times, lower estimated blood loss (EBL), shorter hospital stay, lower rates of overall post-

Table 4.2 Summary of our experience with robotic right colectomy

Demographic	Robotic right colectomy ($n = 100$)
Mean age (range)	70.9 ± 9.38 (38–93)
Mean BMI (range)	28.9 ± 6.86 (19.4–68.8)
Gender	
Female	51
Male	49
Indication[a]	
Adenocarcinoma	47
Adenoma	49
Diverticulitis (right-sided)	2
Crohn's disease	1
Carcinoid	1
Anastomosis	
Extracorporeal	9
Intracorporeal	91
[a]Elective surgery	

Variable studied	Robotic right colectomy ($n = 100$)
Median operative time (range)	186.5 ± 44.5 min (123–336)
Mean estimated blood loss (range)	42.9 ± 57.7 ml (5–300)
Mean extraction site length (range)	4.3 ± 0.88 cm (3–6.5)
Conversions to open surgery (%)	2 (2 %)
Mean specimen length (range)	17.4 ± 6.5 cm (6–37)
Mean lymph node harvest (range)	20.2 ± 9.8 (0–49)
Length of stay (range)	
Mean (days)	3.5 ± 2.7 (1–21)
Median (days)	3

operative complications, and a significantly faster bowel function recovery. Other clinical and oncological outcomes appear to be equivalent. The authors also suggested that future well-designed, prospective, randomized controlled trials were required to better define this technique.

Table 4.4 summarizes the techniques, dissection, anastomosis, operative times, and conversion rate for the largest published series to date [3, 4, 8, 18–23].

In general, a medial-to-lateral dissection technique is the preferred approach [24, 25]. However, in some cases, because of anatomical variations, we start with a lateral-to-medial dissection. At this point, we recommend starting with a medial-to-lateral dissection; however, the surgeon's ability to apply either approach is useful and both seem to be effective. We found that lateral-to-medial dissection is often necessary and feasible and does not require patient repositioning. For example, in the obese patient, it may first be necessary to get adequate length of mesentery, in order to identify, isolate, and transect the ileocolic vessels at their origin.

Table 4.3 Complications

Complication	Robotic right colectomy ($n = 100$)
Urinary retention (UTI)	6 (1)
SSI	
Wound infection	2
Intra-abdominal abscess	1
Ileus	5
PONV/Dehydration[a]	1
Atelectasis, pneumonia	1
Postoperative rectal bleeding (transfusion)	3 (1)
Anastomotic leak[b]	1
30-day mortality	0
Clavien-Dindo	
Grade I:	19
Grade II:	2
Grade III:	2
Grade IV:	0
Grade V:	0

[a] Readmission

[b] Only reoperation—diverting loop ileostomy

Obesity is often cited as one of the main challenges to adoption of minimally invasive techniques. The robot has shown promise and has been empirically shown to overcome those challenges. In our experience with 100 robotic right colectomies, eight patients were obesity class III with a BMI of >40 (range 40.9–68.9). All patients in this subgroup had an intracorporeal anastomosis. Interestingly, there were no complications or conversions in these eight patients. The mean length of stay was 3.3 days. Subjectively, the surgeon did not experience the same fatigue and stress as with laparoscopic procedures on similar BMI procedures. Ergonomic advantages are difficult to quantify beyond anecdotal opinions from expert surgeons, but there seems to be both cognitive and physical stress reduction associated with robotic-assisted surgery [26, 27].

It has been demonstrated that robotic colorectal surgery is associated with longer operative times than conventional laparoscopic colorectal surgery. The meta-analysis by Xu et al. showed that robotic right colectomy had longer operative times than conventional laparoscopic right colectomy [13]. The randomized control trial by Park et al. also showed longer operative times for robotic right colectomy compared to laparoscopic [4]. Our own data also showed longer operative times for robotic right colectomy with a gradual decrease in operative times over time [17].

The mean operative time for a laparoscopic right colectomy as reported in the literature varies from 85 to 214 min [3]. Operative times for robotic right colectomy range from 135 to 266 [3, 4, 8, 18–23]. If we limit the data to laparoscopic right col-

Table 4.4 Data of largest published series of robotic right colectomy

Study (reference)	Year	Country	*N*	# of ports (robot arms)	Anastomosis	Operative time (min)
Rawlings et al.	2007	USA	17	5 (4)	IC	Mean 219
Spinoglio et al.	2008	Italy	18	5 (4)	NR	267[a]
de Souza et al.	2010	USA	40	4 (3)	EC	Mean 159
D'Annibale et al.	2010	Italy	50	5 (4)	IC	Median 224
Deutsch et al.	2011	USA	18	4 (4)	EC	Mean 135
Park et al.	2012	Korea	35	5 (4)	IC	Mean 195
Morpurgo et al.	2013	Italy	48	5 (4)	EC	Mean 266
Casillas et al.	2013	USA	52	NR	EC	Mean 143
Lujan et al.	2015	USA	52	4 (3)	IC	Mean 193
Total			330			Mean 191.75

Study (reference)	LOS (d)	EBL (ml)	Complications (%)	Conversions
Rawlings et al.	5.2	40	3.1	0
Spinoglio et al.	NR	NR	NR	0
de Souza et al.	5	50	15.8	1
D'Annibale et al.	7.0	NR	2	0
Deutsch et al.	4.3	76	10	2
Park et al.	7.9	36	9.0	0
Morpurgo et al.	7.5	NR	23.2	NR
Casillas et al.	6.2	63	32	2
Lujan et al.	3.7	47	19.1	0
Total	Mean 5.85	Mean 52	Mean 14.3	5 (1.8 %)

N number of RRC patients, *RRC* robotic right colectomy, # number, *MtL* medial to lateral, *LtM* lateral to medial, *IC* intracorporeal, *EC* extracorporeal, *NR* not reported
[a] Only last case reported

ectomy with intracorporeal anastomosis, the mean operative times as reported in the literature range from 136 to 190 min [24, 28–30]. In the systematic review mentioned above, the mean operative time for robotic right colectomy with intracorporeal anastomosis was 167 min ($N=210$) [12]. Our operative times ("skin-to-skin") for a robotic right colectomy with intracorporeal anastomosis averaged 186.5 min ($N=100$). Thus, our robotic operative times compare favorably with conventional laparoscopic right colectomy with intracorporeal anastomosis times reported in the literature.

In our series of 100 cases, the mean LOS was 3.7 days. The mean length of stay for the largest series of robotic right colectomies is 5.85 days (Table 4.4). This is significantly lower than laparoscopic right colectomy as reported in the literature according to the meta-analysis [13]. The degree to which accelerated postoperative care management and intracorporeal anastomosis may contribute to faster recovery of bowel function and shorter length of stay is difficult to measure. Regardless, robotic-assisted colorectal surgery seems to be associated with decreased length of stay compared to conventional laparoscopic colectomy as seen in several published series [4, 13, 18, 21, 22].

Blood loss is consistently shown to be less for robotic colorectal surgery [3, 4, 8, 18–22]. The average estimated blood loss (EBL) for the largest series of robotic right colectomy is 52 ml (Table 4.4). The mean EBL in our series of 100 cases was 47 ml.

The mean overall complication rate for RRC is 14.3 for the same studies noted in Table 4.4. According to the meta-analysis by Xu et al., the rate of complications in robotic right colectomy is less than for laparoscopic procedures. There are almost no intraoperative complications reported in comparative studies, with only one patient reported thus far in the literature [12]. Similarly, conversion rates are very low ranging from 0 to 2 %.

The leak rate for our series of 91 RRC with ICA is 1.1 %. When we reviewed our recent outcomes with conventional LRC with ECA, we found a leak rate of 4.5 % ($N = 156$). Although an advantage is suggested for ICA, this did not reach statistical significance. A recent systematic review and meta-analysis tried to answer this question. Cirocchi et al. performed a systematic review and meta-analysis comparing intracorporeal versus extracorporeal anastomosis during laparoscopic right hemicolectomy but concluded that there was not enough data in the literature and, thus, failed to resolve the controversy [31]. If future studies were to confirm that ICA is advantageous (which is still debated), the role of RRC may gain importance, but more data on ECA versus ICA is needed.

We found that the transition from an extracorporeal to intracorporeal anastomosis was facilitated by the robotic platform. The improved surgical dexterity makes the switch to an intracorporeal anastomosis easier, and this may lead to a higher adoption rate for intracorporeal anastomosis, which is not very commonly used in laparoscopic right colectomy today. With an extracorporeal technique, the surgeon is often extracting, transecting, and creating an anastomosis through a small incision. Trying to accomplish this is sometimes difficult especially in the obese patient with a thick abdominal wall. There is probably less traction and tension applied to the colon and the mesentery during an intracorporeal anastomosis, as well as less trauma to the incision, which may translate into less postoperative ileus and fewer complications. Some studies have supported this potential benefit of the intracorporeal anastomosis [24, 28–34]. Grams et al. reported earlier return of bowel function, shorter length of hospital stay, and fewer complications [28]. Hellan et al. found similar outcomes with intracorporeal and extracorporeal anastomosis but shorter incisions with intracorporeal anastomosis [29]. We found shorter incisions associated with ICA in our experience as well. The mean extraction site excision measured 4.6 cm versus 5.3 cm for the intracorporeal vs. extracorporeal anastomosis [17].

Other practical advantages of the intracorporeal anastomosis include the ability to prevent twisting of the mesentery by direct visualization prior to completion of the anastomosis. The ICA technique (which demands the total intracorporeal resection of the specimen) also allows the surgeon to choose where to place the incision for extraction. Recent data have shown that keeping the extraction site off the midline results in decreased risk of hernia. Samia et al. showed an almost twofold increase in risk of incisional hernia when the extraction site was placed in the midline. By using an ICA technique, the surgeon can choose an extraction site off the midline [35].

A cost analysis is beyond the scope of this chapter. At present, it appears that RRC is more expensive than laparoscopic. However, how much more is widely debated and influenced by several factors. A true cost analysis would involve amortizing capital costs and an analysis of the purchasing practices of different institutions and the specific contracts with industry. Furthermore, surgeon preferences and techniques vary and influence the cost of each case. For purposes of discussion here, we assume that large capital costs, including purchase of laparoscopic towers, monitors, robot, and basic equipment, are removed from the equation. If we just compare the cost of robotic disposable devices (specifically, the robotic hot shears, robotic hook, bipolar fenestrated grasper, EndoWrist® One™ Vessel Sealer, and EndoWrist® Stapler 45 System) versus laparoscopic disposables (energy device, endoscopic stapler, linear stapler 75, and reloadable stapler 60), the estimated range difference is from US $400–1000 difference in favor of laparoscopic. In a recent randomized clinical trial, Park et al. concluded that, although feasible, RRC did not provide benefit to justify the greater cost [4]. The authors did state the limitations of the study included few patients and a single surgeon with greater laparoscopic experience. They also stated that future developments in robotic technology would prompt reevaluation of the use of robotics in colon resection. More recently, a meta-analysis has shown several outcome advantages in favor of robotics, which is tipping the scale toward robotics [13]. Furthermore, if operative times improve, instrument use is standardized, and more intracorporeal anastomosis is performed, we may see more use of robotics for right colectomy and a reevaluation of cost benefit.

Robotic Right Colectomy for cancer:

There are very few studies to date addressing the oncologic outcomes with robotic techniques. In their study of 50 consecutive robotic right colectomies for cancer, D'Annibale et al. reported a mean specimen length of 26.7 cm (range 21–50) and a mean lymph node harvest of 18.8 (range 12–44). Disease-free survival was 90 % and overall survival was 92 %. Cancer-related mortality was 8 %. Median follow-up was 36 months (range 6–96). No conversions were reported. They concluded robotic right colectomy was safe and provided adequate oncologic resection with acceptable short-term results [20].

Trastulli et al. reviewed their short-term outcomes with robotic right colectomy with intracorporeal anastomosis for cancer in a series of 20 consecutive patients [38]. Mean specimen length was 32.7 cm (range 26–44) and mean lymph node harvest was 17.6 (range 14–21). No conversions were reported. The authors concluded that the procedure was safe and feasible. Furthermore, intraoperative oncologic resection was adequate; however, the authors did not report recurrence or survival rates.

Because the da Vinci robot is a tool to perform laparoscopic surgery, studies will likely show no difference and no untoward effects as has been demonstrated with laparoscopic right colectomy for cancer [36–38]. It is likely that for robotic right colectomy and partial colectomy, results will be similar to laparoscopic colectomy in terms of adequacy of oncologic resection. Future studies will reveal recurrence rates and long-term survival data.

Table 4.5 Robotic right colectomy for cancer (our results with right colectomy for cancer)

Cancer cases	*N* = 47
Stage	
I	21 (44.7 %)
II	11 (23.4 %)
III	13 (27.7 %)
IV	2 (4.2 %)
Morbidity	
Conversions	1 (2.1 %)
Leak	1 (2.1 %)
30-day mortality	0
Recurrence rate	
Port site	1 (2.1 %)
Anastomosis	0
Distant	0
Survival	
1 year (all stages)	100 %
Mean follow-up (years)	1

To date, we have experience with 47 robotic right colectomies for cancer. Two stage IV patients underwent palliative robotic resection. Table 4.5 summarizes our experience. Mean lymph node harvest was 20.2 ± 9.9 (range 0–49) and mean specimen length was 17.4 ± 6.5 cm (6–37). There was one port site recurrence which was resected a year after her surgery. The original pathology was T4N2M0 in that patient. No other local or distant recurrences have been seen to date at a mean follow-up of 12 months.

Single-Incision Robotic Colectomy (SIRC)

Recently, single-incision techniques have been introduced as an alternative to conventional multiport colectomy. It is an approach that attempts to manipulate the laparoscopic camera and instruments through a single skin incision using a multichannel port. Theoretically, the procedure may reduce port-related complication, decrease postoperative recovery time, and improve cosmesis. Several studies have demonstrated safety and feasibility of single-incision laparoscopy (SIL) in colorectal surgery [39, 40]. However, several challenges remain including long operative times, difficult ergonomics, suboptimal visualization, and lack of advanced instrumentation.

The da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA, USA) has been applied to robotic colectomy. Several case reports and small series have demonstrated the feasibility of SIRC [25, 41–44]. The Robotic Single-Site™ platform, designed for laparoscopic cholecystectomy, was recently shown to be feasible for use in right colectomy [41, 42]. Spinoglio et al. published three case reports of SIRC using the Single-Site™ platform. They successfully performed three robotic right colectomies, two with intracorporeal anastomosis [44].

However, there are limited choices for instrumentation for the Single-Site™ kit. A bipolar Maryland dissector and curved needle driver for the Single-Site kit are due to be released. But despite these advances, the platform in its present state does not have wristed instrumentation severely limiting the advantage of the robotic platform.

Challenges of SILS include surgical instrument collisions due to crowding at the access site, reduced freedom of motion due to parallel straight instruments, and the lack of triangulation. Despite overcoming some drawbacks of SILS by restoring normal triangulation, the Single-Site™ kit does not completely compensate due to the lack of articulating instruments. Thus, most SIRC case reports and small series use da Vinci S-Type Surgical Systems (Intuitive Surgical, Inc., Sunnyvale, CA, USA) in order to have articulating instrumentation. A single-incision port is used (GelPOINT Advanced Access Platform; Applied Medical Inc., Rancho Santa Margarita, CA, USA). Obias et al. reported the experience at a single institution with 59 SIRC [25]. There were eight conversions (13.6 %): four to open (6.8 %), three to multiport robotic (5.1 %), and one to SIL (1.7 %). Conversions were associated with higher complication rates and longer length of stay. The authors concluded that patient selection was important to improving surgical outcomes.

Future studies will help define the benefits and role of SIRC in colorectal resection. SIRC is still new and its use should be limited to carefully selected patients and be performed by experienced and skilled surgeons. Most authors suggest the selection of low BMI patients (≤ 25 kg/m^2) and benign disease if possible during the initial experience and learning curve.

Conclusion

In conclusion, as several authors and we have demonstrated, robotic right colectomy is safe and feasible. Although most comparative studies have shown longer operative times for RRC, operative times for RRC with intracorporeal anastomosis are comparable to conventional LRC with intracorporeal anastomosis. The true advantage of robotics may lie in its ability to simplify complex tasks, and robotics may facilitate the adoption of minimally invasive techniques and ICA in right colectomy. Thus, if future studies confirm that ICA is advantageous (which is still debated), the role of RRC may gain importance, but more data on ECA versus ICA is needed. SIRC is also a technique that is evolving. Newer instrumentation and advanced technology will likely widen its applicability and foster growth in this platform. A recent meta-analysis suggests that RRC may have advantages over LRC. Comparative studies may help define the role of robotics in right colectomy in the near future. Most authors agree that future multi-institutional, randomized, controlled studies are needed to determine whether RRC can provide better outcomes than LRC and justify costs.

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Chapter 5
Robotic Abdominoperineal Resection

Grace S. Hwang, John Gahagan, and Alessio Pigazzi

Introduction

Minimally invasive approaches to colorectal disease and cancer have been largely accepted and new techniques are being explored on several fronts. Robotic and robotic-assisted laparoscopic colorectal dissection is one such area and has become more and more relevant in this field. This approach is especially important for cases requiring precise movements in a limited space, such as in pelvic dissections. The use of the robotic technique has led to improved outcomes and lower rates of conversion and, in some areas, reduced morbidity. In this chapter, we will review our operative techniques of robotic-assisted abdominoperineal resection (APR).

Indications and Contraindications

Currently, the most common indications for APR include:

- Rectal cancer involving the levator ani muscle complex
- Rectal or anal cancer involving the sphincter complex
- Rectal cancer with malignant perirectal fistula
- Recurrent rectal cancer
- Persistent or recurrent anal squamous cell cancer after Nigro protocol

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- Anal adenocarcinoma
- Rectal cancer in patients who are not candidates for sphincter preservation due to poor functional status or comorbidities

Preoperative Workup (Including Images)

The evaluation should start with a thorough history and physical exam, including history of pain, urinary or bowel incontinence, and sexual dysfunction. A digital rectal examination and endoscopy are needed to verify the location of the tumor. A colonoscopy should be performed to confirm the diagnosis and rule out malignant synchronous lesions. Synchronous malignancies have been reported in 2–8 % of cases [1, 2]. Using either the anal verge or dentate line as the starting point, the distance to the lower border of the lesion should be measured.

A CT chest is necessary to exclude pulmonary metastases as well as basal CEA levels. If CEA levels are elevated before surgery, levels should decrease to normal after treatment. Recurrence can be detected postoperatively if levels start to rise again.

Preoperative imaging in rectal cancer is crucial in this day and age due to increasing value of preoperative adjuvant therapies. Adjuvant treatments depend on tumor size, location of lesion, stage, and depth of invasion. The usefulness of obtaining routine CT scans for uncomplicated rectal cancer is controversial, as treatment plan will not usually be affected. However, acquiring baseline CT scan for more advanced disease is helpful in assessing for involvement of adjacent organs. However, the limitations of CT imaging in rectal cancer include inability in evaluating for extent of rectal wall invasion in early stages and inability to assess for lymph node involvement [3, 4]. A recent CT evaluating for liver metastases should also be obtained.

Endoscopic rectal ultrasonography and high-resolution MRI can be used to accurately stage rectal cancer before surgery. These techniques are more accurate in determining depth of invasion and assessing the extent of locoregional spread or fixation to adjacent organs to gauge resectability. MRI is particularly useful to determine the possibility of circumferential margin involvement. Information gathered from these factors can help determine the sequence and type of therapy.

Start the patient on a liquid diet the day before surgery to mechanically cleanse the large bowel. Limited bowel prep may be initiated in the afternoon or evening before surgery. After the colon is evacuated of stool, nonabsorbable antibiotics may be given orally to decrease the rate of postoperative septic complications. Preoperative marking of the stoma site is important to ensure suitable stoma positioning and optimal postoperative care and function.

A single dose of parental antibiotics should be administered within an hour before incision. Thrombosis prophylaxis should start prior to the operation and continue on during the hospitalization [5].

Operative Details

Patient Positioning

The patient is placed in modified lithotomy position using Allen stirrups to allow the perineal portion to be done simultaneously if desired or after abdominal portion without redraping. Place a large foam mat or egg crate on the operating room table directly underneath the patient to prevent patient sliding during steep Trendelenburg. A padded Velcro strap is placed across the patient's chest for further immobilization during lateral position changes. The arms are tucked at the sides and all pressure points are padded to minimize nerve injury. The use of a folded sheet under the lower back will elevate the buttocks slightly off the bed and allow for better access to the posterior portion of the perineal dissection. The patient's buttocks should sit at the edge of the operating table, with hips slightly flexed and abducted.

A Bair Hugger blanket is placed over the patient's chest to prevent intraoperative hypothermia. Foley catheter is inserted to maintain complete urinary drainage throughout the procedure, as well as to assist in identifying the membranous urethra in males during the surgery. The abdomen, perineum, and rectal areas are prepped and draped in the usual sterile manner. The rectum is irrigated with normal saline. In females, a vaginal prep is performed for the vaginal elevator. Reexamination of the pathology is performed by digital rectal exam or flexible sigmoidoscopy. The anus is closed with a purse-string nonabsorbable suture.

The four-armed da Vinci surgical system robot can be docked between the patient's legs or over the left hip in the lateral position. We prefer the left hip approach as it allows access to the perineum during surgery for intraoperative digital/endoscopic examinations as well as transanal extraction of the specimen. In this position, the robot should be aligned with the left anterior iliac spine (ASIS) and the camera port.

Port Setup

A Veress needle is placed at Palmer's point and pneumoperitoneum is established. A 12 mm camera port is placed halfway between the xiphoid process and pubic symphysis. As a deep pelvic dissection is anticipated for this case, the camera port should be placed no farther than 20 cm away from the pubic symphysis after the abdomen is insufflated. Placing the camera port too high on the abdomen will make it difficult to access the deep pelvis at the end of the procedure. The 0° camera is inserted, and the liver, small bowel, and peritoneal surfaces are carefully inspected for evidence of distant metastatic disease. If a large tumor burden is suspected, especially with multiple peritoneal implants, the surgeon should reassess whether to proceed with resection or only perform a colostomy.

Next, three robotic ports are placed under directed visualization. A line is drawn from the camera port to the ASIS on each side, and R1 inserted 8–10 cm from the camera port along this line. A second robotic port R2 is placed just lateral to the camera port about 8–10 cm from it. The third robotic port (R3) is placed 8–10 cm lateral to R2, usually just above the left ASIS.

Two laparoscopic-assisted ports are inserted under direct vision. L1 is placed along the right MCL, about 10 cm superior to R1. L2 is placed halfway between the right MCL and midline, about 10 cm superior to L1. Maintain triangulation in port placement with no less than one handbreadth between trocars. We recommend the robotic ports be placed more medially for patients with a narrower pelvic inlet.

After port placement, the table is placed in steep Trendelenburg (30°) and tilted 10–15° toward the patient's right side. Using atraumatic graspers, mobilize the bowel loops out of the pelvis to clear the operative field. The robot is docked with Arm 1 (R1) in the right lower quadrant, Arm 2 (R2) in the left lower quadrant, and Arm 3 (R3) in the left lateral abdomen. Initial exploration and lysis of adhesions are usually performed laparoscopically.

Details of Procedure

Robotic Mobilization of Sigmoid Colon and Ligation of Vessels

After docking the robot, the sigmoid is retracted anteriorly by the assistant using atraumatic graspers through the epigastric port. The robotic arm will have a monopolar scissor in arm 1, a fenestrated bipolar in arm 2, and a ProGrasp retractor or suction irrigator in arm 3. Medial to lateral dissection is begun at the inferior mesenteric artery (IMA) at the sacral promontory using monopolar cautery. The peritoneum medial to the right common iliac artery is incised and dissection is carried through the mesentery of the sigmoid. Using a combination of sharp and blunt dissection, the avascular plane is entered. The inferior mesenteric pedicle and mesocolon are isolated and elevated off the retroperitoneum. Recognize that the hypogastric nerve plexus, gonadal vessels, ureter, and iliacs lie just posterior to this avascular plane in the retroperitoneum, and dissection is performed while taking care to identify and preserve these structures, sweeping them posteriorly. In most cases, the superior hemorrhoidal artery is identified, isolated, and ligated just distal to the takeoff of the left colic artery. However, if one suspects proximal tumor spread, such as lymph node involving structures outside of the pelvis, the IMA should be ligated about 1 cm from the takeoff of the aorta and IMV ligated between clips or with a vessel-sealing device near the ligament of Treitz. The presacral nerves and ureter should again be reidentified just before vessel ligation. Locate the left ureter through its course over the pelvic brim and down to bladder. It is especially important to identify its course over the left side because the ureter may be close to the root of mesentery of rectosigmoid and may be included in the division of the rectosigmoid unless carefully retracted.

Splenic mobilization is usually not necessary in abdominoperineal resection, as the short segment of colon is able to reach the abdominal wall without additional mobilization for creation of a colostomy. However, in select patients, such as in obese patients, additional mobilization may be needed. In such cases, the lateral peritoneal reflections along the left colon are released using a combination of electrocautery and blunt dissection.

Attention is then placed back into the pelvis, and the dissection is then continued along the right pelvic brim at the sacral promontory for rectal mobilization. Incision is extended down to the pouch of Douglas. Identify the right ureter under the residual peritoneum and its course over the iliac vessels. Often, the sympathetic nerve trunks can be seen posterior to the superior hemorrhoidal artery as the rectal mesocolon is mobilized away from the sacral promontory. The assistant retracts the rectum anteriorly and cephalad, while dissection proceeds posteriorly along the avascular plane, which is between the presacral fascia and the mesorectum. Continue the dissection laterally while identifying the hypogastric nerve plexus and preserving them by gently sweeping them toward the pelvic sidewall and away from the dissection plane. Bear in mind that the preservation of the pelvic nerve plexus and anterior roots of sacral nerves S2-4 is required for urinary and sexual function. The presacral nerve plexus appears as a dense plaque of nerve tissue close to rectum at the level of prostate or upper vagina.

Follow the course of ureter and nerve plexus as dissection is continued down to the levators. For posterior tumors, dissection should go just posterior to Denonvilliers' fascia to spare autonomic nerve function. Anteriorly, the peritoneum overlying the rectovesical/rectovaginal fold is incised to expose Denonvilliers' fascia or the rectovaginal septum. In males, preserve the Denonvilliers' fascia to minimize bleeding from the pampiniform plexus near the seminal vesicles. In females, sharp dissection goes until the rectovaginal septum is visualized. However, if dealing with an anterior or circumferential tumor, try to include the two layers of Denonvillier's fascia in men and the peritoneum at the base of the pouch of Douglas in women. Do not violate the mesorectum, as this may compromise the oncologic resection. Complete mesorectal excision along with distal and circumferential clearance is key to accomplishing a complete oncologic resection. For malignancies, the level of the rectum for the location of transection is marked using ink tattoo preoperatively (and before neoadjuvant chemoradiation if patients require it), and this is visualized at the time of the surgery with endoscopy. Posterior dissection of the rectum is continued toward the midline and the anococcygeal ligament is transected anterior to the coccyx. The lateral dissection involves taking down the lateral attachments using electrocautery and continues on until the medial edge of the obturator fascia. The dissection is carried distally, through the levators, and into the ischiorectal fat just before the perineum (extralevator APR). The levators are resected widely near their insertion to the bony pelvic structures to minimize risk of positive circumferential margin (Figs. 5.1 and 5.2). Robotic-assisted transabdominal resection of the levator muscles allows for a precise dissection of the pelvic floor and no need for repositioning, thus shortening the operative time and diminishing the time for the perineal excision as the patient can be kept in lithotomy.

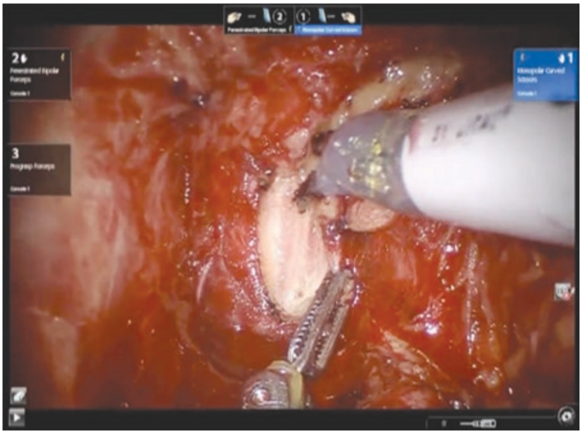

Fig. 5.1 Left lateral dissection of the levator muscle during extralevator APR

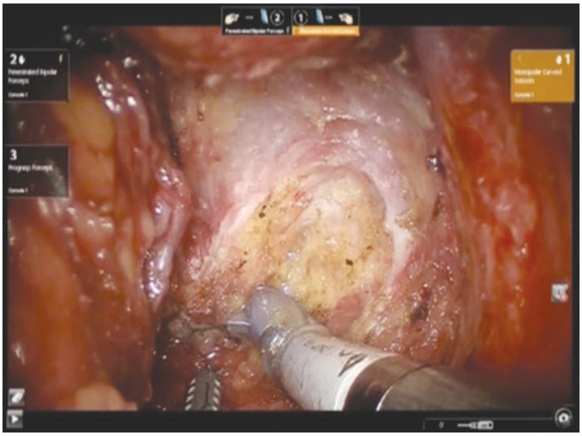

Fig. 5.2 Right lateral dissection of the levator muscle during extralevator APR

After the rectum is fully mobilized, the proximal bowel is divided with laparoscopic staplers at the junction between the left colon and sigmoid, at right angles to the blood supply. The surgeon must ascertain that the proximal colon is able to reach the abdominal wall freely. The completed dissected rectum is tucked into the pelvis to facilitate removal through the perineum. The colon is exteriorized through the left trocar size, and an end colostomy is fashioned in the usual manner.

Perineal Resection

Confirm that patient's condition is satisfactory before proceeding with the perineal excision of the rectosigmoid. With significant blood loss, consider replacing volume lost with blood transfusion. Some prefer the two-team approach so that the perineal excision is carried out simultaneously with abdominal procedure. The robot is undocked.

Historically, Miles placed patient on the left side in modified Sims' position. Some surgeons prefer to change to lithotomy position by adjusting the stirrups to lift the legs. Others prefer the patient in prone-jackknife to complete this portion. When this procedure is performed robotically, the need for dramatic repositioning is eliminated. We prefer to place the patient in steep Trendelenburg. Stabilize the patient's vital signs after the change in position before proceeding with the perineal resection.

The anus is sewn closed with several purse-string sutures to prevent contamination. The skin is prepped again with antiseptic solution. Legs and buttocks are covered with sterile drapes. If dissection from above has been carried down far enough, perineal excision of rectum and anus should be done quickly with minimal blood loss. Outline the incision around the anus with anterior and posterior midline extension. With several Allis clamps, grasp the skin around anal orifice and incision through the skin and subcutaneous tissue at least 2 cm away from closed anal orifice. The incision starts anteriorly at the perineal body and goes laterally to the ischiorectal spines and then posteriorly at the top of the coccyx. After the skin, subcutaneous ischiorectal membrane, and fat are incised, the levators will be visualized. If not already completed during the abdominal portion, use long cautery tip to divide the anococcygeal ligament along the posterior midline near the sacrum. Once connection is established between the abdominal cavity and the perineum, hook your finger above the levator ani muscles toward the perineum and slowly divide with cautery as far from the rectum as possible. Some may prefer to divide the levators with paired clamps. Dissection starts posteriorly and then proceeds laterally and anteriorly. Often, it is best to complete the anterior dissection after the proximal portion of the specimen is everted out of the perineum. Resection should extend into the midperineum. However, in women with anterior tumor, resection should extend into the vagina, removing the posterior wall of vaginal wall. A more radical excision may be needed if the lesion is low and near the anus. After the specimen is delivered, inspect the pelvic space with direct illumination with dry sponges until the field is free of oozing. Irrigate the area.

Closure

The perineal incision is closed in at least two layers. The divided levator ani muscles are normally not closed in case of extralevator APR. A trans-abdominopelvic drain is placed. Subcutaneous and skin layers are closed with very large and widely spaced interrupted vertical mattress sutures, using number 1 nylon or silk, and tied loosely. However, if a large perineal excision is anticipated preoperatively, the surgeon may consider consulting a plastic surgeon as a myocutaneous flap reconstruction with the rectus abdominis muscle may be required. In addition, an internal barrier, such as an omental patch, may be utilized with the perineal wound left open or covered with a negative pressure therapy (i.e., wound vac). The use of V-Y flaps is also encouraged to reduce tension at the perineal flap closure.

The abdomen is re-insufflated and inspected. Reaffirm the location of the ureters. If the patient's anatomy permits, the surgeon may consider creating a pedicled omental flap and laying it into the pelvic defect although this is not normally our practice.

The end colostomy is brought out at the appropriate location. As previously mentioned, the patient should already be marked by the ostomy therapist. The end of the colon is cleaned of any extra fat and an end colostomy is fashioned in the usual manner.

Postoperative Care

For fast-track recovery, oral liquids are started on POD 1 and advanced as tolerated, in the absence of nausea or vomiting. Remove the Foley catheter after 1–2 days for constant bladder drainage. In males, loss of bladder tone can lead to distressing postoperative complications. Clamp trials may be utilized to determine if patient is maintaining sensation of full bladder. Some opt for cystometric study before removing the catheter. After Foley removal, avoid overdistension by checking post residual volume every 4–6 h depending on fluid intake. Consider reinsertion of urinary catheter if patient experiences frequent urination of small volume. Urology consultation may be considered for further assistance.

Early patient mobilization is encouraged to minimize risk of DVT, improve lung function, and stimulate GI function. Remove abdominopelvic drain in a few days when output markedly decreases. Patient should be instructed on colostomy care before being discharged home.

Possible Complications

The complications of abdominoperineal resection can be summarized as vascular, organ, and nerve injury. Hemorrhage may be due to injury to the presacral venous plexus, the iliac vessels, inadequate ligature of the vascular stalks, mesenteric tear, or the gonadal vessels. Trauma to the ureters, duodenum, bladder, or male urethra must be prevented. Injury to the pelvic nerves may result in bladder dysfunction, urinary retention, ejaculation failure, and impotence [6]. The ureters and the lateral ligaments of the rectum are to be traced deep into the pelvis by careful dissection without elevation before dividing the colon or vessels. Rectal perforation during the perineal dissection is also very common, occurring in 62 % of reported cases, and is associated with higher rates of local recurrence [7]. The risk of surgical site infection is as high as 20 %, especially after neoadjuvant chemoradiation therapy.

Follow-Up

Patients should follow up with their surgeon on outpatient basis at 4 weeks from discharge. The perineal wound should be inspected for signs of appropriate healing, with additional follow-up scheduled as needed. A repeat CEA level should also be checked to confirm normal levels. PET-CT scans are done once a year for the first 3 years postoperatively. Colonoscopic surveillance also should start about 1 year from diagnosis.

Tips and Tricks

- Maintain triangulation when placing ports, with no less than one handbreadth between trocars.
- For patients with very narrow pelvic inlet, place robotic ports more medially.
- Keep dissection within the avascular presacral space and minimize the use of electrocautery or other high-energy-based devices to avoid injury to the autonomic nerves. Do not remove the endopelvic fascia. If bleeding occurs, use thumbtacks, bone wax, oxidized cellulose, or pressure with a surgical packing.
- To reduce the incidence of genitourinary dysfunction, pay meticulous attention to the anterior plane of dissection.
- Maintain visualization of both ureters.
- When access to the base of the mesentery is difficult, as in obese patients or small patients with small intra-abdominal domain, a medial to lateral approach may be very difficult to accomplish. In these cases, a lateral to medial approach may be considered.
- In cases of locally advanced anal or low rectal cancer, a perineal reconstruction may be necessary. Patients with history of neoadjuvant chemoradiation therapy are more prone to complications such as abscess or very slow healing surgical wounds and may benefit from perineal closure with pedicle flaps. A vertical rectus abdominis myocutaneous (VRAM) flap can be used and is one of the more popular surgical options when flap coverage is needed. The anterior rectus sheath is incised with skin paddle, subcutaneous fat, and rectus muscle layer, which is then mobilized and rotated to reach the pelvic floor.

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Chapter 6
Robotic Low Anterior Resection of Rectal Cancer

Se-Jin Baek and Seon-Hahn Kim

Introduction

Similar to robotic prostatectomy, the advantage of robotic technology in the field of colorectal surgery is best represented during a low anterior resection, which is performed in a narrow and deep pelvis and is difficult to approach [1, 2]. As the procedure of low anterior resection is divided into two segments, the colonic and pelvic phases, two types of robotic procedures have been developed. The first procedure, a hybrid technique, utilizes the robot only in the pelvic phase, during which its advantage is maximized. Conventional laparoscopy is used during the colonic phase. In the second procedure, a totally robotic technique, the robotic system is used throughout both phases (Fig. 6.1). Totally robotic technique can be further characterized by a single or dual docking method. Each approach method requires optimized port placement, cart positioning, and appropriate docking. The surgical method of approach can be selected by operator's preference and familiarity for the procedure.

Hybrid Technique

Hybrid technique was adopted during the early stages of robotic rectal surgery and has been the most widely used procedure to date. One important reason that the utilization of a robot during rectal surgery was relatively delayed was that the range

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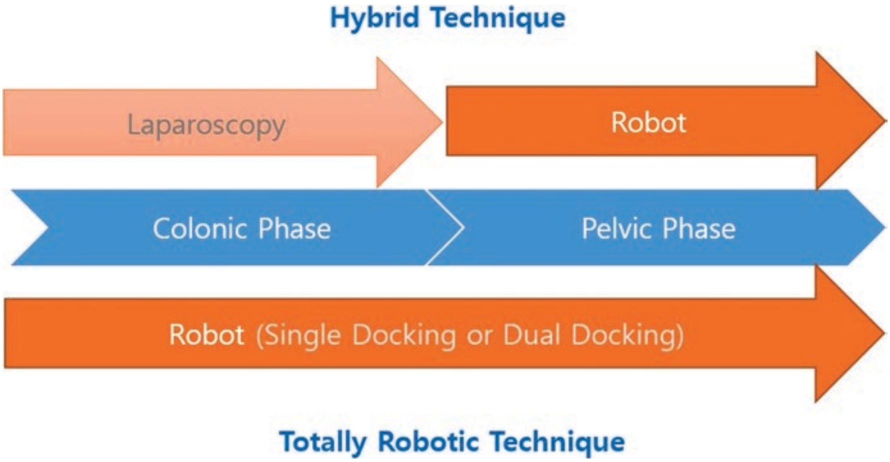


Fig. 6.1 Hybrid technique versus totally robotic technique

of the operation is wide over the pelvis to splenic flexure [3–7]. The up-and-down and left-to-right movements over a wide dissection field frequently resulted in the external collision of robotic arms during the surgery. Moreover, multiquadrant operations such as a low anterior resection require the relocation of the robotic cart, a time-consuming and difficult procedure as the robotic devices are heavy and bulky. Consequently, surgeons felt stressed and hesitated to apply a robot system toward rectal surgery. However, a hybrid technique, which concentrated solely on the pelvic dissection, otherwise known as total mesorectal excision (TME), was developed to facilitate the whole procedure more effectively and to reduce overall operation time by eliminating the need for repositioning of the robotic cart [4, 5, 7]. As a result, this technique lowered the barrier to entry for many surgeons and enabled the robotic system to be rapidly adopted in the field of rectal surgery.

Port placement in the hybrid technique is designed not only to focus on robotic pelvic dissection but also to be available for laparoscopic colonic mobilization during the second phase of a low anterior resection. The current recommendations are as follows:

Patient Positioning and Preparation

- This is the step common to all approach methods.
- Patient is in 15°. Trendelenburg position with legs in adjustable stirrups (stirrups mounted at most distal point on operation room (OR) table rail) (Fig. 6.2).
- Patient is tilted right-side down 10–15°.
- Use pads for pressure points and bony prominences, and secure body position, especially on the right side, to avoid shifting.

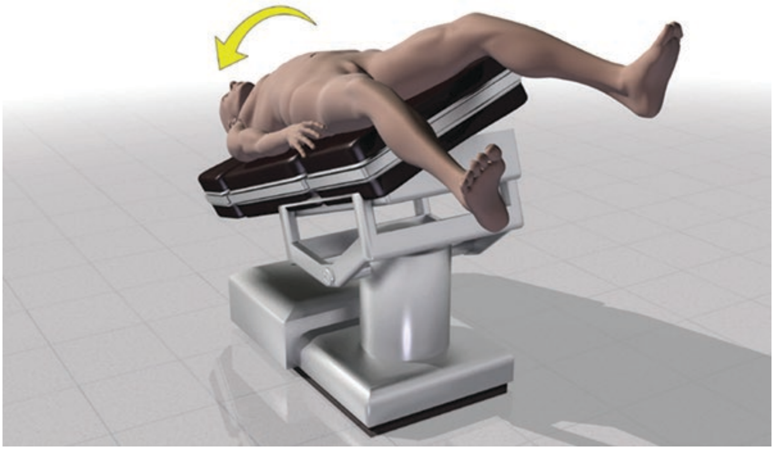


Fig. 6.2 Patient positioning ©2015 Intuitive Surgical, Inc. used with permission

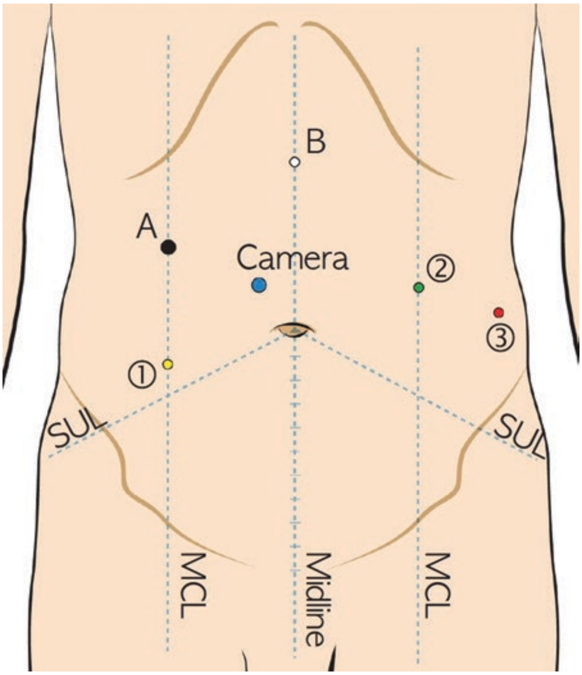
Port Placement

All port placement measurements must be made after insufflation is achieved. Make sure to position the remote center (thick black band) of the *da Vinci* cannula at the level of peritoneum, making the band invisible on either side of the abdominal wall.

- *da Vinci Camera Port, 12 mm* (*blue*): Place port 3–4 cm to the right of and 2–3 cm above the umbilicus. Distance to symphysis pubis should be approximately 22–24 cm (Fig. 6.3).
- *da Vinci Instrument Arm ① Port, 8 or 13 mm* (*yellow*): Place a minimum of 8 cm from the camera port, on the right midclavicular line (MCL), 2–3 cm above the right spinoumbilical line (SUL). If stapler access from this location is deemed necessary, dilate this port to a 13 mm *da Vinci* cannula.
- *da Vinci Instrument Arm ② Port, 8 mm* (*green*): Place port at the level of the camera port on the left MCL. The distance to the other instrument ports and camera port should be at least 8–10 cm.
- *da Vinci Instrument Arm ③ Port, 8 mm* (*red*): Place approximately 4 cm above the left anterior iliac spine. The distance to Instrument Arm ② Port should be at least 8 cm.
- *Assistant Port* (*A*), *5 mm* (*black*): Place port 8–10 cm superior to Instrument Arm ① on right MCL (a minimum of 8 cm from camera port).
- *Assistant Port* (*B*), *5 mm* (*white*): Place port 6–8 cm inferior to xiphoid process on the midline. The distance to the other instrument ports and camera port should be at least 8–10 cm.

*Slight modifications to the port locations may be necessary due to patient's anatomy.

Fig. 6.3 Port placement for hybrid technique ©2015 Intuitive Surgical, Inc. used with permission



Patient Cart Positioning and Docking

- After the colonic phase is finished using standard laparoscopy, the patient cart is positioned and docked with all instrument arms.
- Position camera arm setup joint on the opposite side of the *da Vinci* Instrument Arm ③.
- Lower OR table and raise all of the arms high enough to clear the patient's abdomen. Push all overhead lights and equipment aside.
- Align the center column and camera arm with the camera port along a straight line following over the left stirrup mounting clamp on the OR table (Fig. 6.4a). The sterile person directing the roll-up can use a straight laparoscopic instrument to line up the camera port and stirrup clamp as an aid in directing the person rolling up the patient cart.
- Roll up the patient cart at approximately a 45° angle. The patient cart base should straddle the corner of the OR table (depending on OR table model).
- Use port and arm clutch maneuvers to dock the camera and instrument arms (Fig. 6.4b).
- Maximize spacing between all instrument arms.

CAUTION: Once the patient cart is docked and connected to the cannulae, the operating room table cannot be moved.

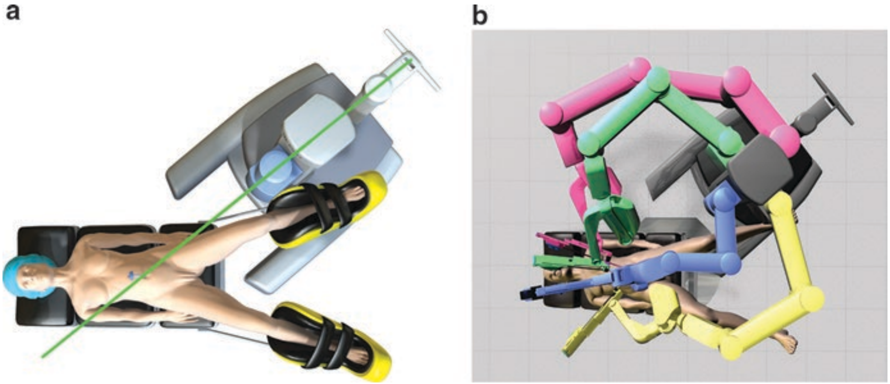


Fig. 6.4 Patient cart alignment (**a**) and docking (**b**) ©2015 Intuitive Surgical, Inc. used with permission

Procedure Steps

In hybrid technique, standard laparoscopy is used in steps 1–4, and then robotic procedure is performed in steps 5–6:

- Step 1: Initial exposure—Flip the greater omentum over the transverse colon toward the liver. Retract small bowel loops out of the pelvic area into the right upper quadrant. Suspend uterus in female patient.
- Step 2: Primary vascular control—Primary vascular control is achieved by dividing the inferior mesentery artery (IMA) and the inferior mesenteric vein (IMV).
- Step 3: Medial to lateral mobilization of sigmoid and descending colon—Extent of the dissection is superior to the inferior border of the pancreas, laterally following Gerota's fascia and inferior to the psoas muscle where the ureter crosses the iliac vessels.
- Step 4: Splenic flexure mobilization—To achieve a tension-free anastomosis, the splenic flexure is mobilized in a medial approach.
- Step 5: Rectal dissection—The rectal dissection is performed using an elliptical dissection pattern of the posterior first, continuing laterally to the left side, then to the right, and finally to the anterior side of the rectum down to the levator ani muscle level.
- Step 6: Rectal division and anastomosis—Performed in standard laparoscopy or alternatively with robotic assistance. Prep through minilaparotomy at left lower quadrant port location.

Operative Outcome

Because the procedure was developed early and has been widely used, there are many reports for low anterior resection using the hybrid robotic technique. Most operative outcomes, such as blood loss, conversion rate, hospital stay, and complications, after robotic low anterior resection using hybrid technique were similar or better than results after laparoscopic or open low anterior resection with the exception of operative time (Table 6.1) [3–18]. Moreover, several articles have reported comparative operative time results between the robot and laparoscopic groups, which may reflect upon the merit of hybrid robotic technique in the matter of time saving [19–25]. Recently, long-term oncologic outcomes were reported to indicate comparable overall and disease-free survival between robot and laparoscopic procedures [26].

Totally Robotic Technique

Single Docking Method

The hybrid technique has contributed much toward the adoption of the robot system in rectal surgery. However, there are some limitations of forgiving the advantages of using a robot system during the colonic phase, which provides better visualization during lymphovascular dissection around the inferior mesenteric artery (IMA) and the convenience of splenic flexure mobilization [27–29]. Thus, other procedure was independently developed to utilize the robotic system throughout both phases of a low anterior resection.

Initially, the totally robotic procedure was performed as a two-stage or a three-stage technique, which necessitated multiple cart repositionings, a time-consuming process. Subsequently, a single docking totally robotic technique was developed and has been widely used to date. This method consists of stationing the robotic cart beside the left lower quadrant of the patient's abdomen, allowing complete coverage of the wide operative field, from the stage of splenic flexure mobilization to pelvic dissection, without requiring cart repositioning [27–29]. As a result, the advantages of robotic system could be maximized both in colonic and pelvic phase, and operative time could be saved compared to a two- or a three-stage technique. Moreover, this approach allows for a transanal procedure such as colonoscopic examination, even in the situation that the robotic cart is docking [29]. In the hybrid technique, the robotic cart was initially located between the patient's legs, but has recently been repositioned to the left lower quadrant of the patient's abdomen because of the advantages described above.

Port placement in single docking method was designed to cover the entire operation, including colonic mobilization and pelvic dissection (steps 1–6). The current recommendations are as follows below. Note that patient positioning, preparation, cart positioning, and docking are the same as in the other techniques.

Port Placement

Position the remote center (thick black band) of *da Vinci* cannula at the level of the peritoneum. Maintain at least 8 cm between robotic ports and Assistant Ports:

Table 6.1 Operative outcomes after robotic low anterior resection using a hybrid technique

Author (year)	Type of article	Cases	Operative time (mean(±SD), min)	Estimated blood loss (mean(±SD), ml)	Conversion rate (%)	Hospital stay (mean(±SD), days)	Complication (%)	Mortality (%)	Note
Pigazzi et al. (2006) [3]	Comparative case report (robot vs. laparoscopy)	12 (R, 6; L, 6)	R, 4.4; L, 4.3 (p=NS)	R, 104; L, 150 (p=NS)	–	R, 45; L, 3.6 (p=NS)	R, 16; L, 16.7 (p=NS)	–	First report
Hellan et al. (2007) [8]	Case series	39	285	200	–	4	12.8	0	
Baik et al. (2008) [9]	Comparative analysis (RCT) (robot vs. laparoscopy)	36 (R, 18; L, 18)	R, 217.1 (51.6); L, 204.3 (51.9) ($p=0.477$)	–	R, 0; L, 11.1 ($p=0.486$)	R, 6.9 (1.3); L, 8.7 (1.3) ($p<0.001$)	R, 16.7; L, 5.6		
Baik et al. (2009) [10]	Comparative analysis (robot vs. laparoscopy)	113 (R, 56; L, 57)	R, 190.1 (45.0); L, 191.1 (65.3) ($p=0.924$)	–	R, 0; L, 10.5 ($p=0.013$)	R, 5.7 (1.1); L, 7.6 (3.0) ($p=0.001$)	R, 10.7; L, 19.3 ($p=0.202$)	–	
Park et al. (2010) [12]	Comparative analysis (robot vs. laparoscopy vs. open)	263 (R, 52; L, 123; O, 88)	R, 232.6 (52.4); L, 158.1 (49.2); O, 233.8 (59.2) ($p<0.001$)	–	R, 0; L, 0; O, NA	R, 10.4 (4.7); L, 9.8 (3.8); O, 12.8 (7.1) ($p<0.001$)	R, 19.2; L, 12.2; O, 20.5 ($p=0.229$)	R, 0; L, 0; O, 1.1 ($p=0.373$)	
deSouza et al. (2011) [13]	Comparative analysis (robot vs. open)	82 (R, 36; L, 46)	R, 337.9 (81.8); L, 273.8 (10.8) ($p=0.003$)	R, 187.5 (98.1); L, 273.8 (165.4) ($p=0.036$)	–	R, 7.0 (5.8); L, 7.3 (4.1) ($p=0.74$)	R, 30.6; L, 32.6 ($p=0.84$)	R, 2.8; L, 2.2	

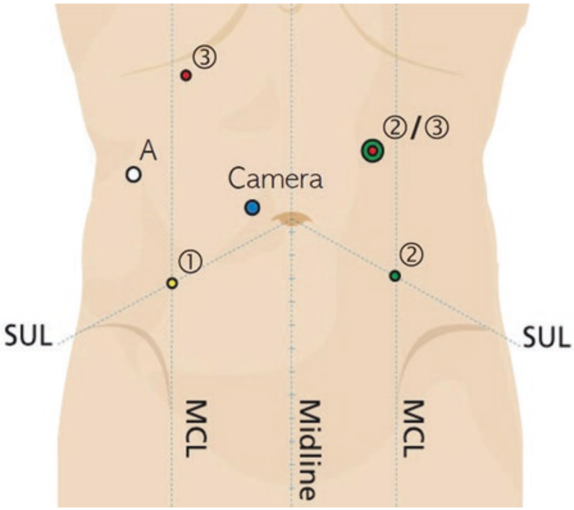
(continued)

Table 6.1 (continued)

Author (year)	Type of article	Cases	Operative time (mean(±SD), min)	Estimated blood loss (mean(±SD), ml)	Conversion rate (%)	Hospital stay (mean(±SD), days)	Complication (%)	Mortality (%)	Note
Park et al. [26] (2014)	Comparative analysis (robot vs. laparoscopy)	217 (R, 133; L, 84)	R, 205.7 (67.3); L, 208.8 (81.2) ($p=0.766$)	R, 77.6 (153.2); L, 82.3 (185.8) ($p=0.841$)	R, 0; L, 7.1 ($p=0.003$)	R, 5.86 (1.43); L, 6.54 (2.65) ($p=0.035$)	R, 7.5; L, 9.5 ($p=0.602$)	–	5-year OS, R, 92.8 %; L, 93.5 % ($p=0.829$); 5-year DFS, R, 81.9 %; L, 78.7 % ($p=0.547$); 5-year cumulative LR, R 2.3 %; L, 1.2 % ($p=0.649$)

SD standard deviation, *RCT* randomized controlled trial, *R* robot, *L* laparoscopy, *O* open, *NS* not specific; *NA* not applicable, *OS* overall survival, *DFS* disease-free survival, *LR* local recurrence

Fig. 6.5 Port placement for single docking method ©2015 Intuitive Surgical, Inc. used with permission



- *da Vinci Camera Port*, *12 mm* (*blue*): Place the port 3–4 cm to the right of and 3–4 cm above the umbilicus. Distance to symphysis pubis should be approximately 22–24 cm (Fig. 6.5).
- *da Vinci Instrument Arm ① Port, 8 mm* (*yellow*): Place the port a minimum of 8 cm from the camera port, on the right spinoumbilical line (SUL) at the crossing of the midclavicular line (MCL). Distance to symphysis pubis should be approximately 14–16 cm. Alternatively, the 13 mm stapler cannula with a 13–8 mm reducer can be used in this port location for introduction of the linear stapler.
- *da Vinci Instrument Arm ② Port, 8 mm* (*green*): Place the port a minimum of 8 cm from the camera port, on the left spinoumbilical line (SUL) at the crossing of the midclavicular line (MCL). The distance to the symphysis pubis should be approximately 14–16 cm.
- *da Vinci Instrument Arm ③ Port, 8 mm* (*red*): Place the port approximately 3 cm below the right costal margin and approximately 2 cm medial to the right MCL.
- *da Vinci Instrument Arm ②/③ Port, 8 mm* (*green-red)*: Place the port 7–8 cm below the left costal margin, slightly medial to the left MCL. Place the port a minimum of 8 cm from the other instrument ports and the camera port.
- *Assistant Port* (*A1*), *5 mm*: Place the port 8–10 cm cephalad to the Instrument Arm ① Port and approximately 4 cm lateral to the right MCL (a minimum of 8 cm from the camera port). This port is used for suction/irrigation, ligation, and retraction.

Port Usage and Instrument Arm Setup per Procedure Step

- Initial procedure steps 1–3 on patient's left side are performed in a four-arm setup with arms 1, 2, and 3 connected (Fig. 6.6a).

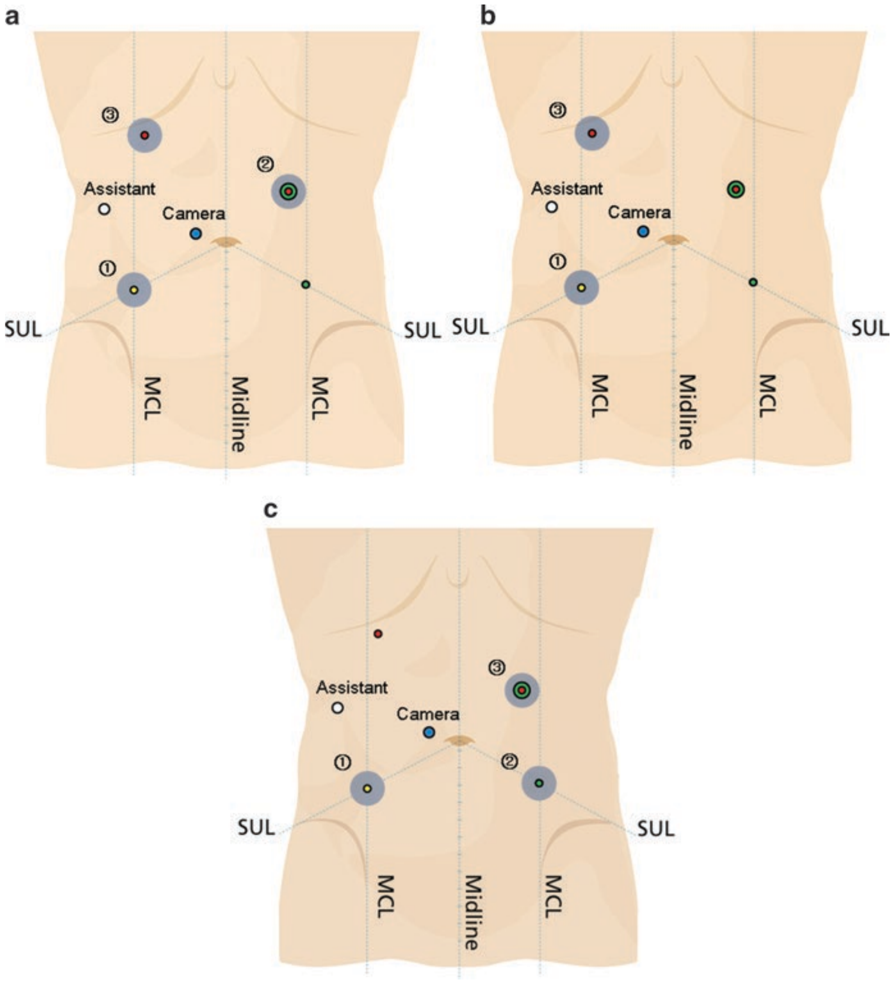


Fig. 6.6 Left lateral setup (steps 1–3) (**a**), splenic flexure setup (step 4) (**b**), and pelvic setup (steps 5 and 6) (**c**) ©2015 Intuitive Surgical, Inc. used with permission

- Splenic flexure mobilization (step 4) is performed in a three-arm setup with only instrument arms 1 and 3 connected to minimize external collisions (Fig. 6.6b).
- Pelvic procedure steps 5 and 6 are again performed in a four-arm setup with instrument arms 2 and 3 reconnected in the lower and upper left *da Vinci* instrument ports (Fig. 6.6c).

Operative Outcome

Similar to the hybrid technique, most results from totally robotic low anterior resection with single docking method were comparable or better than results from a conventional laparoscopic or open low anterior resection (Table 6.2) [27–35].

Table 6.2 Operative outcomes after robotic low anterior resection using a single docking method

Author (year)	Type of article	Cases	Operative time (mean(±SD), min)	Estimated blood loss (mean(±SD), ml)	Conversion rate (%)	Hospital stay (mean(±SD), days)	Complication (%)	Mortality (%)	Note
Hellan et al. (2009) [27]	Case report	2	–	–	–	–	–	–	First report
Choi et al. (2009) [29]	Case series	50	304.8	–	0	9.2 (3.9)	18	–	
Hara et al. (2014) [41]	Case series	200	270	190	0	–	38.5	–	5-year OS, 92.0 %; 5-year DFS, 81.7 %; 5-year local pelvic control, 95.0 %
Bianchi et al. (2010) [30]	Comparative analysis (robot vs. laparoscopy)	50 (R, 25; L, 25)	R, 240; L, 237 ($p=0.2$)	–	R, 0; L, 1	R, 6.5; L, 6 ($p=0.4$)	R, 16; L, 24 ($p=0.5$)	–	
Kim et al. (2012) [31]	Comparative analysis (robot vs. open)	200 (R, 100; O, 100)	R, 188 (45); O, 103 (23) ($p<0.001$)	–	R, 0; O, NA	R, 7.1 (2.1); O, 6.9 (1.5) ($p=0.308$)	R, ~ 26; L, ~ 27	R, 0; O, 0	
Koh et al. (2014) [34]	Comparative analysis (robot vs. HAL)	38 (R, 19; HAL, 19)	R, 390; HAL, 225 ($p<0.001$)	–	R, 5.3; HAL, 10.5 ($p=0.180$)	R, 7; HAL, 6 ($p=0.476$)	R, 15.8; HAL, 36.8 ($p=0.269$)	R, 0; HAL, 0	
Levic et al. (2014) [35]	Comparative analysis (robot vs. single-port laparoscopy)	92 (R, 56; SL, 36)	R, 247; SL, 295 ($p=0.055$)	R, 50; SL, 35 ($p=0.59$)	R, 5.4; SL, 0 ($p=0.29$)	R, 8; SL, 7 ($p=0.037$)	R, 23.3; SL, 27.8 ($p=0.62$)	R, 0; SL, 5.6 ($p=0.15$)	

(continued)

Table 6.2 (continued)

Author (year)	Type of article	Cases	Operative time (mean(±SD), min)	Estimated blood loss (mean(±SD), ml)	Conversion rate (%)	Hospital stay (mean(±SD), days)	Complication (%)	Mortality (%)	Note
Yoo et al. (2014) [43]	Comparative analysis (ISR only) (robot vs. laparoscopy)	70 (R, 44; L, 26)	R, 316.4 (65.1); L, 286.8 (51.5) ($p=0.038$)	R, 239.8 (278.6); L, 215.4 (247.3) ($p=0.813$)	–	R, 11.4 (5.6); L, 11.0 (6.3) ($p=0.509$)	R, 38.6; L, 26.9 ($p=0.436$)	–	3-year OS, R, 95.2 %; L, 88.5 % ($p=0.174$); 3-year RFS, R, 76.7 %; L, 75.0 % ($p=0.466$)
Ghezzi et al. (2014) [42]	Comparative analysis (robot vs. open)	174 (R, 65; O, 109)	R, 299.0 (58.0); O, 207.5 (56.5) ($p<0.001$)	R, 0; O, 150 ($p=0.002$)	R, 1.5; O, NA	R, 6; O, 9 ($p<0.001$)	R, 7.7; O, 6.4 ($p=0.764$)	–	5-year OS, R, 85.0 %; O, 76.1 % ($p=0.569$); 5-year LR, R, 3.2 %; O, 16.1 % ($p=0.024$); 5-year DFS, R, 73.2 %; O, 69.5 % ($p=0.734$); 5-year CSS, R, 86.6 %; O, 78.3 % ($p=0.565$)

SD standard deviation, *ISR* intersphincteric resection, *R* robot, *L* laparoscopy, *O* open, *SL* single-port laparoscopy, *HAL* hand-assisted laparoscopy, *NA* not applicable, *OS* overall survival, *DFS* disease-free survival, *RFS* recurrence-free survival, *LR* local recurrence, *CSS* cancer-specific survival

Again, it was found that operative time was significantly longer than conventional surgery. However, based on recent studies, the operative time has decreased after an initial learning curve [36–40]. To date, favorable mid- and long-term oncologic outcomes have been reported, and long-term outcomes for totally robotic low anterior resection with single docking method are currently being studied [41–43].

Dual Docking Method

Conventional laparoscopic splenic flexure mobilization has been reported to be technically demanding and is associated with greater intraoperative blood loss, complications, and a longer operative time and hospitalization period than robotic surgery because of decreased range of motion, instrument tremors caused by a longer distance between the trocar site and the target organ, and the fulcrum effect [44–46]. Although totally robotic technique has an advantage in splenic flexure mobilization versus conventional laparoscopy or the hybrid technique, it is still difficult because the number of active robotic arms is decreased from three to two at that time in order to avoid external collision (Fig. 6.6b) [27, 29, 47]. Consequently, a modified two-stage totally robotic technique (often referred to as the dual docking method) was proposed, which involves both redocking and reorientation during the procedure to enable easier splenic flexure mobilization [48]. This method involves rotating the operating table instead of moving a heavy robotic cart which is technically challenging and time-consuming and is thus more convenient and efficient than a conventional two-stage robotic technique.

Port placement in the dual docking method is suitable for a wide range of patients that need complete splenic mobilization and avoids external collision between the camera and the main acting port. The current recommendation is as follows below. Again, note that patient positioning and preparation are the same as in other techniques and robotic approach is performed in all steps (1–6).

Port Placement

All port placement measurements must be made after insufflation is achieved. Make sure to position the remote center (thick black band) of the *da Vinci* cannulae at the level of peritoneum, making the band invisible on either side of the abdominal wall. Distance between ports should be at least 8 cm:

- *da Vinci Camera Port*, *12 mm* (*blue*): Place port 2–3 cm above the umbilicus on the midline (Fig. 6.7a, b).
- *da Vinci Instrument Arm ① Port, 8 mm* (*yellow*): Draw a line from the approximate location of the splenic flexure across the camera port down to the right anterior superior iliac spine (ASIS). This is known as the “splenic flexure line.” Place port approximately 2 cm inferior to this line and slightly medial to the right midclavicular line (MCL).

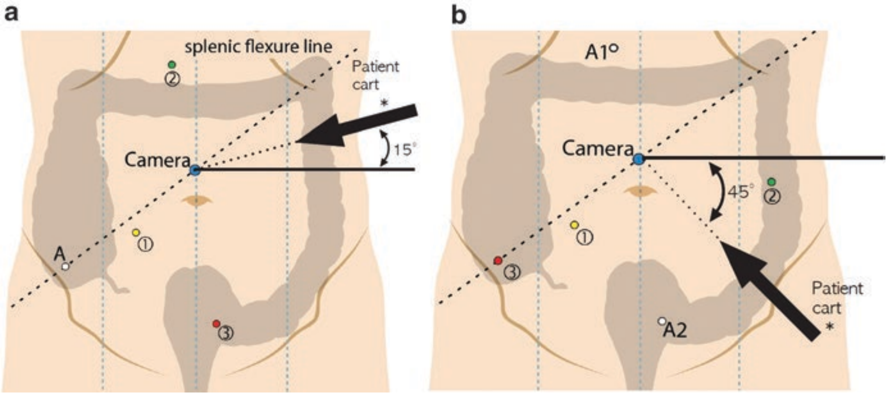


Fig. 6.7 Port placement for dual docking method at stage 1 (colon mobilization) (**a**) and stage 2 (rectal dissection) (**b**) ©2015 Intuitive Surgical, Inc. used with permission

- *da Vinci Instrument Arm ② Port, 8 mm* (*green*):
  - For stage 1: Place this port in the epigastric area, 2–3 cm right lateral to the midline and just below the right costal margin. If the transverse colon needs to be mobilized all the way to the midline, place this port even more lateral toward the right side of the patient. This port location is used as an Assistant Port in stage 2 (A1) (Fig. 6.7a).
  - For stage 2: Place this port at the level of the umbilicus and about 3–4 cm lateral to the left MCL (Fig. 6.7b).
- *Assistant Port* (*A*), *8 mm da Vinci Port*: Place port 2–3 cm above the right ASIS on the splenic flexure line. This port is used as the *da Vinci* Instrument Arm ③ Port in stage 2.
- *da Vinci Instrument Arm ③ Port, 8 mm* (*red*):
  - For stage 1: Place this port just above the pubic bone, 2–3 cm to the left of the midline. This port can be used as an Assistant Port in the second stage (A2) for stapling the rectum and may alternatively be converted to a mini-Pfannenstiel incision for specimen extraction (Fig. 6.7a).
  - For stage 2: dock *da Vinci* Instrument Arm ③ to previously placed Assistant Port (A) utilized in stage 1 (Fig. 6.7b).

Patient Cart Positioning and Docking

- During stage 1 (colonic mobilization), the patient cart is positioned over the left flank, approaching the patient at about 15° (Fig. 6.8a).
- To transition from stage 1 to stage 2, undock the *da Vinci* arms and pull the patient cart straight back; rotate the operating room table about 60° counter-clockwise until a 45° angle is created between the patient cart and the operating

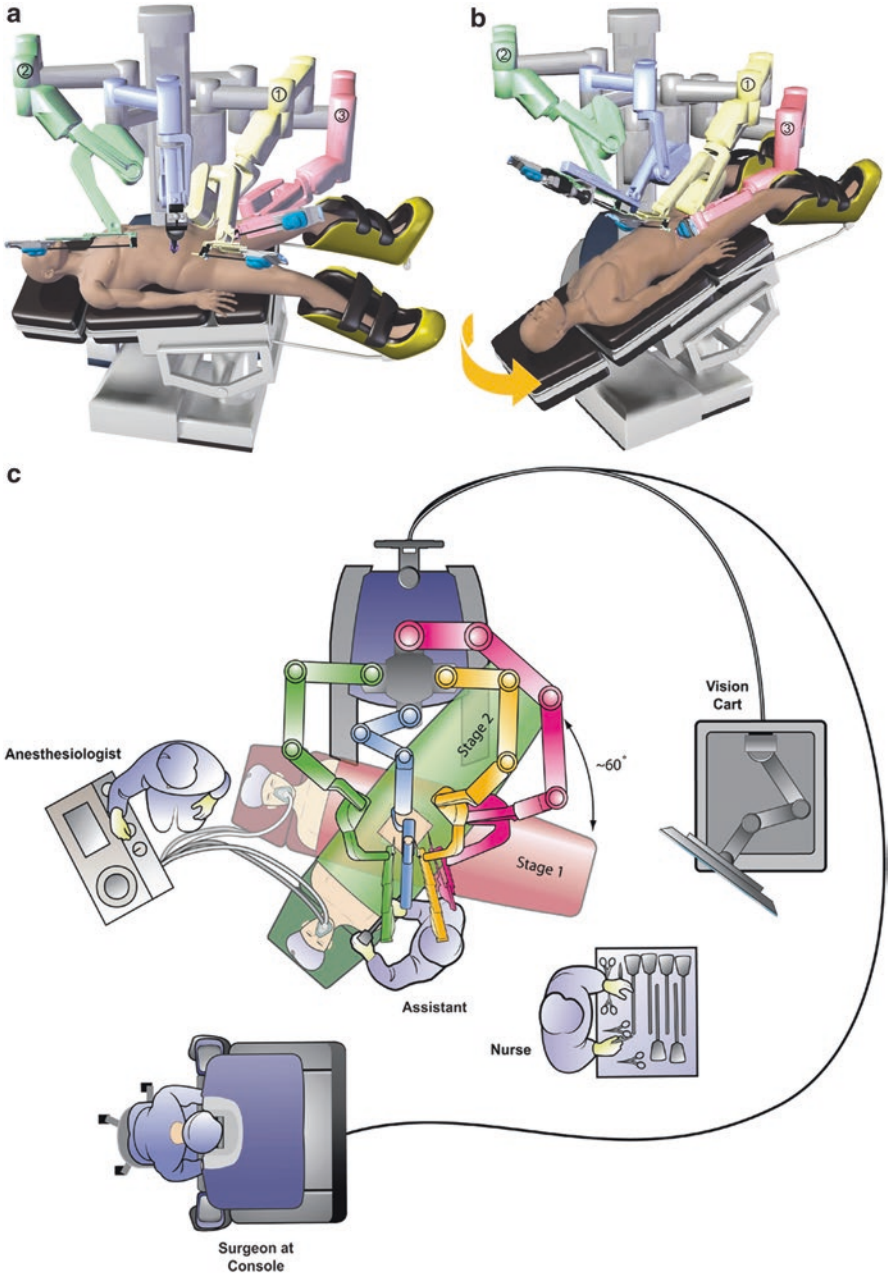


Fig. 6.8 Patient cart positioning for dual docking method at stage 1 (**a**), stage 2 (**b**), and operation room layout (**c**) ©2015 Intuitive Surgical, Inc. used with permission

Table 6.3 Operative outcomes after robotic low anterior resection using a dual docking method

Author (year)	Type of article	Cases	Operative time (mean(±SD), min)	Estimated blood loss (mean(±SD), ml)	Conversion rate (%)	Hospital stay (mean(±SD), days)	Complication (%)	Mortality (%)	Note
Bae et al. (2014) [48]	Case series (including left colectomy)	61	227	20	0	7	31	0	First report

SD, standard deviation

room table. Finally, push the patient cart back in straight and redock the *da Vinci* arms. Alternatively, rotate the patient cart if the operating room table cannot be moved; rotate the patient cart (Fig. 6.8b).

- During the transition, the angle of Trendelenburg can be increased for enhanced exposure of the pelvis. Additionally, the right-sided patient tilt can be returned to a flat position to reorient the pelvic anatomy.
- Ensure the patient's right leg is positioned low enough to prevent interference with *da Vinci* Instrument Arm ③.
- Position the camera arm setup joint on the opposite side of *da Vinci* Instrument Arm ③.

Operative Outcome

There is one report for totally robotic low anterior resection with dual docking method (Table 6.3) [48]. As for the other techniques, this study showed comparable operative outcomes including operative time.

Port Placement for New Robot System

Recently, a new robot system named as *da Vinci Xi*® was released, which has an entirely different surgical platform from conventional *da Vinci S*® or *Si*®. Because *da Vinci Xi*® has a boom-mounted system with the flexibility of a mobile platform and a larger range of motion of robotic arms, we are expecting better accessibility and flexibility of cart positioning, and the development of a new port placement protocol will be necessary.

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Chapter 7
Robotic Total Colectomy

Cesar Santiago and Sean Satey

Introduction

Before the introduction of multi-quadrant access robotic platforms, performing robotic colorectal surgical procedures that required access to multiple quadrants was a challenge. Older robotic platforms, such as the standard, S, and Si, were designed to work in only one quadrant. Most robotic platforms utilized in the United States and other countries are designed as single-quadrant access platforms. This chapter addresses how to perform a multi-quadrant operation, such as a subtotal or total colectomy, with a platform designed to work in a single quadrant. We will describe the optimal locations for the robotic platform and ideal use for the robotic arms via multiple dockings or "port hopping" for each step of the procedure. Technical pearls of each procedural step will be highlighted for the benefit of the reading surgeon.

Background

In 2000, the da Vinci® system was approved by the FDA as the first robotic system to be used in general laparoscopic surgery. Among its first reported uses were esophageal and pancreatic surgery at Ohio State University and robot-assisted cardiac surgery at the Cleveland Clinic in Florida [1]. The use of the robot was later extended to prostatic and urologic procedures as the platform allowed operating in

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narrow and confined spaces. Initial attempts to perform robotic colorectal procedures were unsuccessful since the procedures required multi-quadrant access. The first robotic colorectal surgery was performed in 2001. Weber et al. reported three robotic right and sigmoid colectomies for benign disease using the da Vinci® robotic system [2]. Simple procedures, such as a sigmoidectomy, were difficult to perform; the short instruments and single-quadrant access made mobilization of the proximal descending colon and splenic flexure arduous. The introduction of the S platform in 2008 advanced the role of the robot in colorectal surgical procedures. The release of the Si platform further enhanced the ease at which multi-quadrant procedures could be performed and the use of robotic technology was extended to the realm of colorectal surgery.

Subtotal or total colectomies are common multi-quadrant procedures that may be efficiently performed with the assistance of a robot designed for use in a single quadrant. Subtotal colectomy resects part of the colon, whereas a total colectomy resects the entire colon with sparing of the rectum. The most common indications for subtotal colectomies include polyposis syndromes with rectal sparing, Lynch syndrome, synchronous colonic lesions or tumors, and inflammatory bowel disease [3, 4]. Less common indications include colonic inertia and Hirschsprung's disease [5, 6].

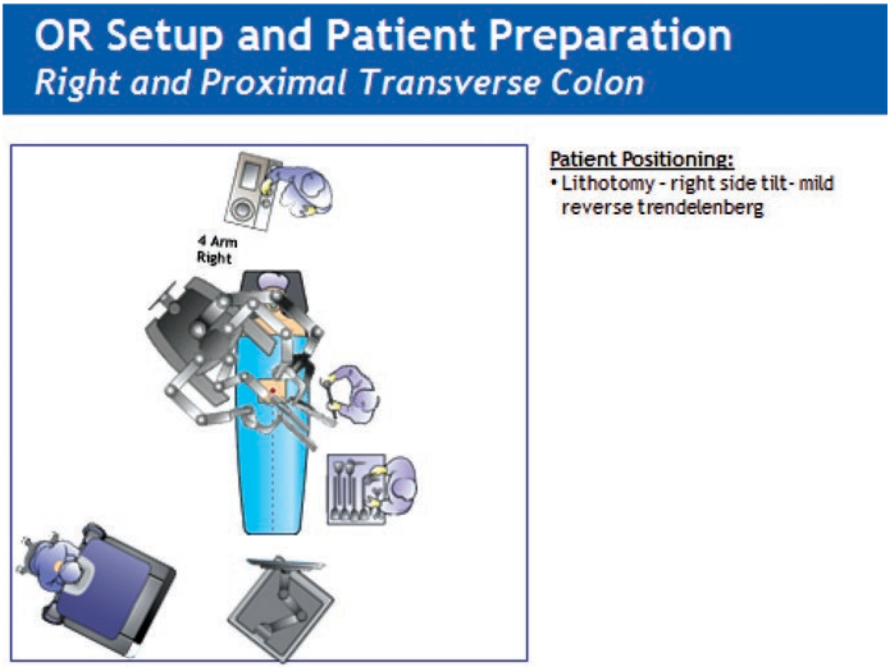
We believe that robotic subtotal or total colectomies should be performed after the operating surgeon is proficient with less complex robotic cases and toward the end of the operating surgeon's learning curve. Recent literature reports that the learning curve for robotic colorectal procedures would be achieved after approximately 15–25 cases [7].

Operating Room Setup and Preparation

Utilization of a dedicated robotic operating room (OR) has become the norm when performing advanced robotic procedures, such as subtotal and total colectomies. The room must be large enough to house both the robotic platform and console while accommodating platform movement to other quadrants, if needed. The possibility of a dual robotic console and the need for a colonoscopy cart should also be entertained. In addition, a dedicated robotic OR ensures a consistent team that facilitates efficiency, decreases OR time, and decreases cost [8]. Fully integrated robotic ORs now enable the surgeon to record the procedure for educational and/or research purposes and offer the ability to perform tele-surgery.

The operating surgeon should be mindful of the room configuration, including entryways, doors, and anesthesia equipment to ensure the most ergonomic setup. A subtotal colectomy performed with an Si platform, for instance, requires more than one docking and requires all of the above considerations.

We prefer to start our subtotal colectomies with dissection of the right colon first; thus, the robot is initially docked over the patient's right shoulder. This setup places



OR Setup and Patient Preparation

Right and Proximal Transverse Colon

Patient Positioning:

- Lithotomy - right side tilt- mild reverse trendelenberg

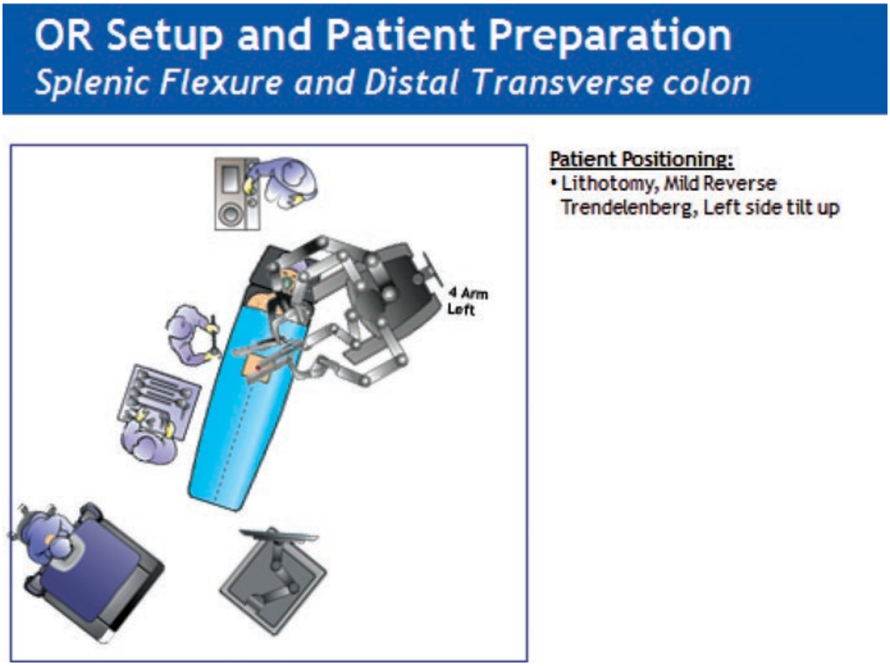
Fig. 7.1 OR setup and patient preparation—right and proximal transverse colon. Patient is placed in lithotomy position with right side tilt in mild reverse Trendelenburg. The robotic second arm is placed ipsilateral to the fourth arm and extended over the patient's head

the robot's second arm ipsilateral to the fourth arm and extended over the patient's head, as illustrated in Fig. 7.1.

The anesthesia cart is positioned at the head of the patient's bed. The anesthesiologist must utilize tubing long enough to allow rotation of the patient in any direction necessary to accommodate the robotic platform. We advise the operating surgeon to sit on the right side of the patient, positioned toward the feet, to ensure direct view of the robotic arms and assistant at all times; thus, we advise against surgeon positioning behind the platform.

The first assistant should sit on the left side of the patient to avoid injury from the moving camera. We also recommend the use of a two-way radio between the surgeon and first assistant to prevent breach of communication. The surgical technician is positioned on the left side of the first assistant to pass instruments as needed. The tower and robotic power source is located at the foot of the table. Two monitor slaves are required and may be relocated depending on the surgical quadrant.

When performing procedures that require multiple positions, it is imperative to secure the patient to the operating table to prevent sliding. Surgical beanbag positioners may be used to prevent movement. If used, care must be taken to ensure that the lateral sides of the beanbags do not interfere with the third robotic arm.



OR Setup and Patient Preparation

Splenic Flexure and Distal Transverse colon

Patient Positioning:

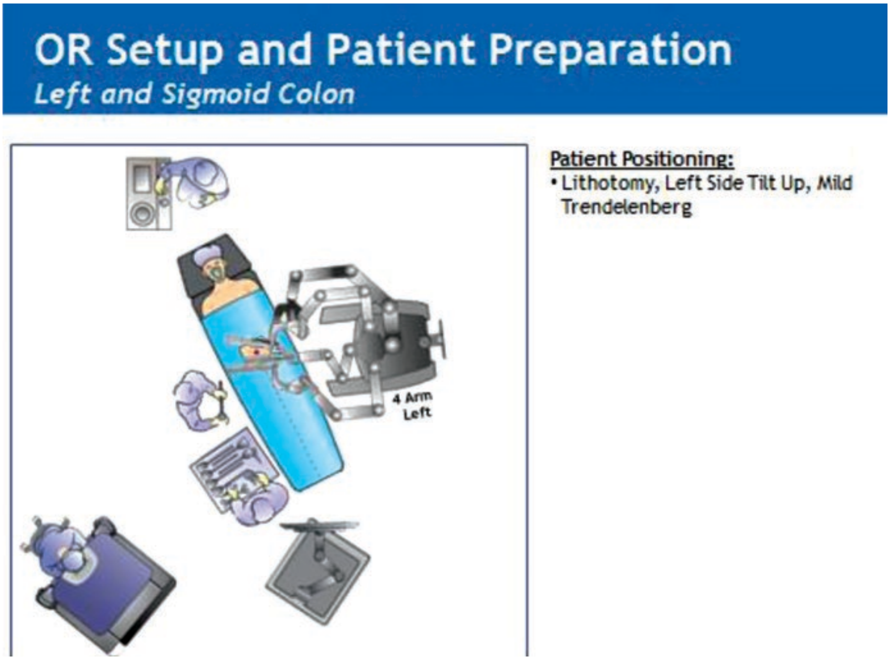
- Lithotomy, Mild Reverse Trendelenberg, Left side tilt up

Fig. 7.2 OR setup and patient preparation—splenic flexure and distal transverse colon. Patient remains in lithotomy position with left side tilt up and in mild reverse Trendelenburg. The robot is re-docked over the patient's left shoulder

Prior to docking of the robot, the ileocolic vessel and duodenum are identified laparoscopically. The initial portion of the robotic procedure—right colon mobilization and hepatic flexure mobilization—requires a few degrees of reverse Trendelenburg and tilt to the right. The same position is maintained until the mid to distal transverse colon is reached. Once reached, the robot is re-docked over the patient's left shoulder, as illustrated in Fig. 7.2. The patient remains in mild reverse Trendelenburg. The distal transverse colon, splenic flexure, and a significant amount of proximal and descending colon are subsequently dissected.

The final stages of the procedure—accessing the distal descending colon to the rectosigmoid junction—require turning the patient on an axis and brining the platform over the left hip at a 45° angle, as illustrated in Fig. 7.3. The patient is then placed in a Trendelenburg position with the patient's left side up. This facilitates movement of the small bowel out of the pelvis and to the right of the right iliac vessel until the inferior mesenteric vessels are identified.

We caution against prolonged steep (25–45°) Trendelenburg position to prevent significant physiologic consequences, such as pulmonary edema, exacerbation of ventilation/perfusion mismatch, and upper airway and brain edema [9]. The wristed arms of the robot allow for precision which make the dangerous practice of steep Trendelenburg virtually unnecessary.



OR Setup and Patient Preparation

Left and Sigmoid Colon

Patient Positioning:

- Lithotomy, Left Side Tilt Up, Mild Trendelenberg

Fig. 7.3 OR setup and patient preparation—left and sigmoid colon. Patient remains in lithotomy position with left side tilt up and in mild reverse Trendelenburg. The patient is turned on an axis, and the platform is moved over the left hip at a 45° angle

Trocar Placements

Multiple quadrant access is required for this procedure. The operating surgeon must be cognizant of the procedural steps to minimize trocar placement despite multiple dockings. We suggest port addition as the surgery progresses to accomplish this goal. The initial trocar configuration mimics that of a right hemicolectomy. The configuration will then emulate that of an isolated splenic flexure lesion and finally a sigmoidectomy. The camera port will remain in the midline in order ensure equal access to all quadrants.

The camera port is placed in the midpoint between the xyphoid process and the pubis. The surgeon must avoid placing the camera port too low to ensure visualization of the hepatic and splenic flexures over the transverse colon and, at the same time, avoid placing the camera too high to circumvent the falciform ligament and prevent obscure visualization of the operative field. The camera port may be moved laterally, in either direction; however, that practice may place the camera too close to the target in subsequent steps of the operation and should be avoided.

The first arm trocar is placed to the left of the midclavicular line, as illustrated in yellow in Fig. 7.4. The second arm trocar is placed at the midpoint between the

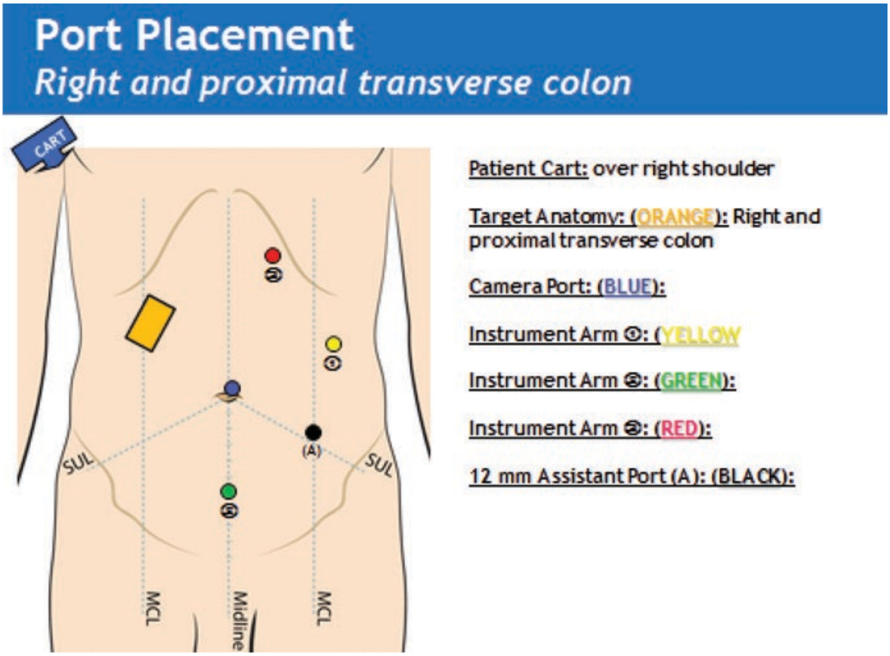


Fig. 7.4 Port placement—right and proximal transverse colon. Target anatomy is referenced in *orange*. Camera port is referenced in *blue* and is placed at the midpoint between xyphoid process and pubis. Instrument arm 1 is referenced in *yellow* and is placed to the left of the patient's midclavicular line. Instrument arm 2 is referenced in *green* and is placed at the midpoint between the camera port and the pubis. Instrument arm 3 is referenced in *red* and is placed to the left of the falciform ligament. The 12-mm assistant port is referenced in *black* and is placed at the midpoint between the first and second instrument arms

camera port and the pubis. We prefer to make this incision horizontally in preparation for our extraction site. The third arm trocar is placed to the left of the falciform ligament. The surgeon must take care to allow adequate distance for access to the gastrocolic ligament. The assistant port is placed at the midpoint between the first and second arms after making sure that the robotic camera will not interfere with the assistant's hand. This trocar configuration will allow the operating surgeon to reach the level of the proximal to mid-transverse colon.

The second stage of the operation involves the dissection of the mid-transverse colon, splenic flexure, and proximal descending colon. Once again, the robotic platform is re-docked over the patient's left shoulder. A 12-mm assistant port is added in the right lower quadrant at the midpoint between the camera port and the iliac spine. During the second stage, this port will serve as the assistant port; during the final stage of the procedure, it will become the first arm. An 8-mm port is added to the right upper quadrant, as illustrated in red in Fig. 7.5, which will now serve as the second arm.

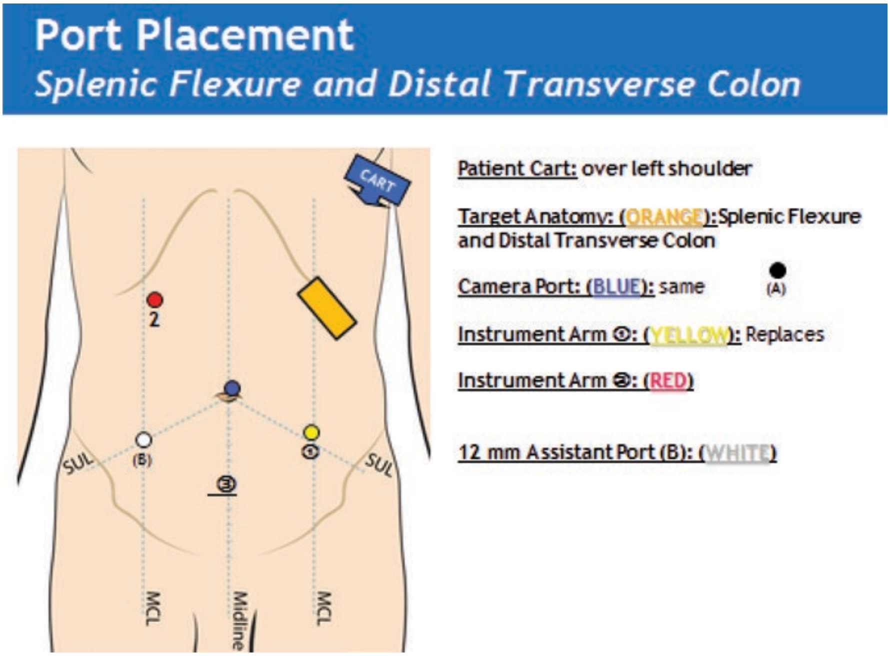


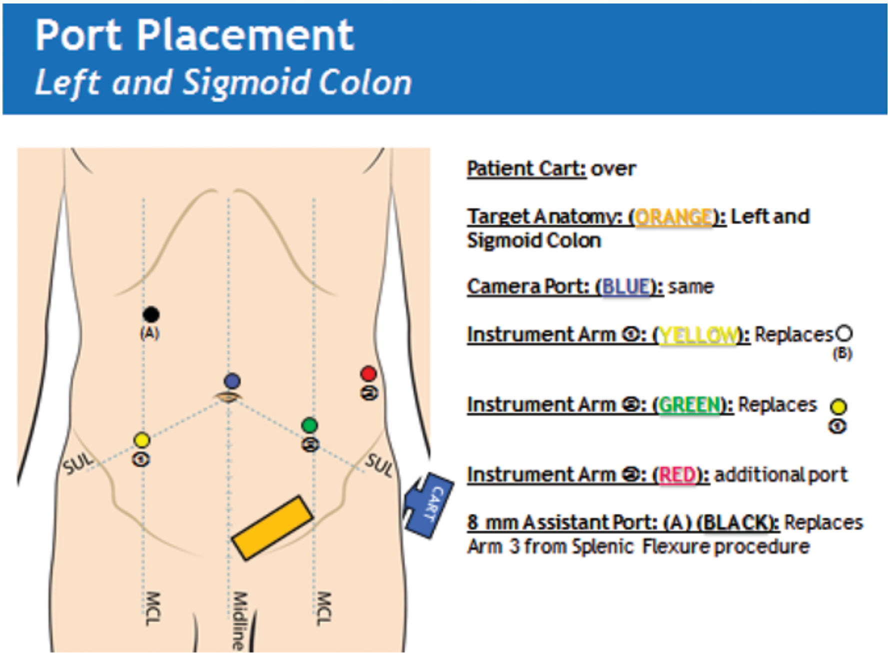
Fig. 7.5 Port placement—splenic flexure and distal transverse colon. Target anatomy is referenced in *orange*. Camera port remains the same as Fig. 7.4. Instrument arm 1 is referenced in *yellow* and is re-docked at the previous left lower quadrant assistant port site. Instrument arm 2 is referenced in *red* and is placed to right of the patient's midclavicular line. Instrument arm 3 is referenced in *clear* and is re-docked at the previous site of instrument arm 2 in Fig. 7.4. The 12-mm assistant port is referenced in *white* and is placed at the midpoint between the second and third instrument arms

At this point, the first arm is docked on the previous left lower quadrant assistant port site. The third arm is docked in the suprapubic area where the second arm was docked previously.

For the final stage of the procedure, the patient is turned on an axis with the platform over the patient's left hip at a 45° angle. The distal descending colon, sigmoid colon, and rectosigmoid junction are accessed with the following trocar configuration, as illustrated in Fig. 7.6.

The first arm is re-docked at the site of the right lower quadrant assistant port. The second arm may be placed in two possible areas: remain docked on the right upper quadrant where it was previously or re-dock at the left lower quadrant where it was previously the first arm with the robotic platform over the right shoulder.

The third arm is re-docked close to the left anterior axillary line. This is where the first arm was docked at the beginning of the case. Alternatively, an additional 8-mm trocar may be added if the previously placed port is not in an optimal position to be used as the third arm.



Port Placement
Left and Sigmoid Colon

Patient Cart: over

Target Anatomy: (ORANGE): Left and Sigmoid Colon

Camera Port: (BLUE): same

Instrument Arm ①: (YELLOW): Replaces ○ (B)

Instrument Arm ②: (GREEN): Replaces ● ①

Instrument Arm ③: (RED): additional port

8 mm Assistant Port: (A) (BLACK): Replaces Arm 3 from Splenic Flexure procedure

Fig. 7.6 Port placement—left and sigmoid colon. Target anatomy is referenced in *orange*. Camera port remains the same as Figs. 7.4 and 7.5. Instrument arm 1 is referenced in *yellow* and is re-docked at the previous right lower quadrant assistant port site. Instrument arm 2 is referenced in *green* and may remain docked as placed in Fig. 7.5 or may be re-docked to the left lower quadrant port site. Instrument arm 3 is referenced in *red* and is re-docked at the previous site of instrument arm 1 in Fig. 7.4. The 12-mm assistant port is referenced in *black* and is re-docked at the previous site of instrument arm 3 in Fig. 7.5

Docking

The surgeon must make sure that the bed is in the correct orientation, that proper safety belt or beanbag is employed, and that the patient is positioned in a modified lithotomy position for access to the peritoneum, as needed, prior to docking. Platform location is dictated by the quadrant in which the surgeon is operating.

In the case of a subtotal colectomy, we prefer to start with the right colon. Thus, the platform is placed at the patient's right shoulder and toward the patient's head to ensure that the third arm can clear the patient's head. When docking the robot, the surgeon must align the robotic spine, camera arm, and camera shoulder while ensuring that the robot is neither docked too far nor too close to the patient.

Care should be taken to ensure that the blue arrow is in the middle of the marked areas, especially if single docking procedures are to be attempted. Prior to docking, a brief laparoscopic inspection should be performed in order to expose the anatomy; this is especially important if organs are to be retracted toward the opposite quadrant to where the platform will be docked. The operating surgeon must understand that the S and Si platforms are designed to work in one quadrant. For this reason, exposures such as mobilizing the small bowel out of the pelvis and/or to the right upper quadrant must be achieved prior to docking the platform, especially if the platform is to be docked over the left hip.

The surgeon also needs to make sure that the robot's four joints are divided equally on each side. This will ensure that three joints will not be on a particular side of the robot; usually, this happens when the third arm is moved from one side of the patient to the other. Prior to starting the procedure, the robot should be placed in a position that will only require advancement forward toward the patient to facilitate docking and efficiency.

Operative Steps

In the next section, the operative steps are described in an effort to standardize the subtotal colectomy procedure and to make it reproducible for the reading surgeon. Tips, tricks, and extraction sites are also discussed. The following operative steps are our personal preferences and do not need to be followed in the exact order described. The operative steps depend on the surgeon's preference and level of comfort.

Subtotal colectomy operative steps
1. Laparoscopic inspection, exposure, and docking
2. Isolation and division of the ileocolic artery
3. Mobilization of the right colon and hepatic flexure
4. Division of the middle colic pedicle
5. Re-docking for dissection of the distal transverse colon, splenic flexure, and proximal colon
6. Final docking for distal descending colon and rectosigmoid mobilization and transection
7. Extraction, anastomosis, and leak test

1. *Laparoscopic inspection, exposure, and docking*
   The surgeon gains access to the abdominal cavity via his/her technique of choice: Hasson, Visiport, Veress needle, etc. The surgeon then inspects the anatomy and obtains the necessary exposure. The ileocolic artery and duodenum must be identified. The robot is then docked.
2. *Isolation and division of the ileocolic artery*
   After identification of the duodenum, the ileocolic artery is skeletonized and divided. Care is taken to prevent injury to the duodenum.
3. *Mobilization of the right colon and hepatic flexure*
   A medial to lateral dissection is performed. The right colon and hepatic flexure are mobilized. A lateral to medial dissection is performed to connect both planes.

4. *Division of the middle colic pedicle*
   The middle colic vessels are approached from the left side of the patient, skeletonized, and divided with a vessel sealer or energy source of choice. Additional dissection is performed and the proximal transverse colon mesentery and omentum are divided.
5. *Re-docking for dissection of the distal transverse colon, splenic flexure, and proximal colon*
   The robot is docked over the patient's left shoulder. Trocars are added as described above to mobilize the distal transverse colon, splenic flexure, and proximal colon.
6. *Final docking for distal descending colon and rectosigmoid mobilization and transection*
   The patient is turned on an axis to allow the robot platform to extend over the patient's left hip at a 45° angle. This enables reach to the distal descending and sigmoid colon. The rectosigmoid junction is divided using a robotic stapler on the first arm (which is docked in the right lower quadrant).
7. *Extraction, anastomosis, and leak test*
   The specimen is extracted through a Pfannenstiel incision, and an anastomosis is created under direct visualization. Rigid proctosigmoidoscopy is performed to assess the integrity and level of the anastomosis.

Description of Operative Steps

1. *Laparoscopic inspection, exposure, and docking*
   The operating room is set up to ensure proper positioning of the operating table and robotic platform. The operating table is turned on a counterclockwise axis to facilitate robotic docking over the patient's right shoulder. The robot is positioned in a manner to ensure forward advancement in one direction at the time of docking. The distance between the xyphoid process and the pubis is measured. A 12-mm camera port is placed at the midpoint after pneumoperitoneum is established, under direct visualization. The initial abdominal cavity entry technique depends on the surgeon's preference. We prefer the Veress needle technique. After midline camera placement, the initial laparoscopic inspection is performed—either with a laparoscopic or robotic camera. A second 8-mm trocar is placed at the midpoint between the pubis and camera site. A third 8-mm trocar is placed slightly to the left side of the left midclavicular line; this becomes the first arm. A fourth 8-mm trocar is placed in the left upper quadrant to the left of the falciform ligament; this becomes the third arm. The assistant port, either 5- or 8-mm trocar, is placed in the left lower quadrant between the first and second arms.

   The patient is positioned with the right side elevated and in mild reverse Trendelenburg position to expose the ileocolic artery and duodenum. Laparoscopically, the omentum is positioned in the left upper quadrant over the transverse colon. The small bowel is retracted toward the pelvis and left upper quadrant to expose the duodenum. The robot is then docked over the patient's right shoulder. The surgeon must pay close attention to the patient's head when docking the third arm and make sure that the sweet spot is correct. The instruments in the first, second, and third arms include a hook cautery, a Cadière grasper, and a double fenestrated grasper, respectively. We prefer the use of a 30° camera; however, a zero-degree scope may be used as well.

2. *Isolation and division of the ileocolic artery*
   Gentle traction on the ileocecal junction exposes the ileocolic artery. The ileocolic artery should be the first branch seen on the mesentery from the duodenum. Care should be exercised to not confuse the ileocolic artery with the superior mesenteric artery. The anatomic landmark of this procedural step is the duodenum. Once the artery is identified, upward traction is executed by the third arm and is dissected using the first and second arms. Medial to lateral dissection is performed until the duodenum is identified. At that point, the vessel is divided using the vessel sealer or energy source of choice. Similarly, a medial to lateral dissection can be performed to expose the duodenum and the ileocolic artery. Approximately 10–15 % of patients have a true right colic artery that may need to be divided [10, 11].
3. *Mobilization of right colon and hepatic flexure*
   After division of the ileocolic artery, the pedicle stump can be retracted with the third arm. This allows for traction to perform a medial to lateral dissection to mobilize the colon from the retroperitoneal structures, including the Gerota's fascia, duodenum, ureter, and gonadal vessels. The dissection is first extended toward the abdominal wall. The dissection is then extended toward the hepatic flexure until the liver is identified from a medial to lateral approach. Next, the colon is mobilized from a lateral to medial approach. The third arm draws the cecum toward the left upper quadrant, while the first and second arms work together to divide the peritoneal attachments from the terminal ileum and white line of Toldt toward the hepatic flexure. The gastrocolic ligament is opened with a vessel sealer on the first arm and the aid of the third arm. The dissection planes are connected and the hepatic flexure is mobilized, exposing the middle colic vessels.
4. *Division of the middle colic pedicle*
   The middle colic vessels are approached from the left side of the patient. We prefer making a mesenteric window to the left of the main vessel trunk for two reasons. First, this allows identification of the mesenteric leaflet and vessels. Second, in the case of inadvertent bleeding when dividing the middle colic vessels, the surgeon has a mesenteric window to help control bleeding while minimizing the risk of injury to the duodenum and/or superior mesenteric artery. Once the vessels are divided, current platform limitations require the surgeon to re-dock and reposition the robot over the patient's left shoulder.
5. *Re-docking for dissection of the distal transverse colon, splenic flexure, and proximal colon*
   An 8-mm trocar is placed in the right upper quadrant or mid-abdomen to the right of the midclavicular line. This trocar will serve as the second arm when the

robot is moved to the other side of the patient. The robotic platform is then re-docked to the patient's left side in order to gain access to the splenic flexure. A 12-mm assistant port is then placed on the right lower quadrant at the midpoint between the camera and iliac spine.

Once re-docked, the second arm is placed on the right upper abdomen; the fist arm is docked at the site of the previous left-sided assistant port; and the third arm is docked on the suprapubic trocar site which will eventually serve as the extraction site. The patient is placed in reverse Trendelenburg position. The first, second, and third arms are equipped with a vessel sealer, double fenestrated grasper, and Cadière grasper, respectively. The equipment on arms 1 and 2 may be interchanged without compromising efficiency.

The mesentery of the mid to distal transverse colon is divided using the vessel sealer. The assistant applies traction on the transverse colon toward the patient's feet to gain exposure. The assistant and third robotic arm aid with exposure. The splenic flexure, proximal descending colon, and mesentery are mobilized in the same fashion, alternating the first and third arms for retraction and dissection as needed.

6. *Final docking for distal descending and rectosigmoid mobilization and transection*
   The robot is undocked and the patient is turned on an axis such that the robotic platform is at a 45° angle from the patient's left hip. The patient is placed with the left side up and minimal Trendelenburg position in order to expose the inferior mesenteric vessels. The first arm is docked on the right lower quadrant port which was previously the assistant port. The second arm is docked at the previous site of the first arm. The third arm is docked on the port site closest to the left anterior axillary line, as needed. Alternatively, the second arm may be docked on the right upper abdomen. This is the location at which the second arm was previously docked for the splenic flexure mobilization. The third arm may be docked at the site of the first arm; this provides access to the descending, sigmoid, and rectosigmoid colon.

   After division of the descending colon mesentery, the mesorectum of the rectosigmoid junction is skeletonized using a combination of the vessel sealer and hook cautery. Once completed, the second arm is undocked, and the 12-mm port is replaced with a 13-mm port to fit the robotic stapler. The robotic arm is then re-docked, and the robotic stapler with smart clamp technology is used to divide the rectosigmoid. A single fire of a blue load staples is usually sufficient to divide the bowel. If the tissue is thick, green load staples may be utilized. In our practice, the stapler tends to work better if used away from the camera rather than turning it toward the operative field due to its articulation limit. The remainder of the mesorectum is divided with the vessel sealer in the standard fashion. We do not recommended sealing the same location with the vessel sealer twice in order to prevent denaturing of the seal and subsequent bleeding.

7. *Extraction, anastomosis, and leak test*
   The specimen is extracted via enlarging the suprapubic port site and creating a Pfannenstiel incision. We advocate for a Pfannenstiel incision due to its low rate of incisional hernias when compared to midline extraction sites [12, 13]. The

first arm is undocked and a wound protector is placed prior to extraction. The terminal ileum is divided with a cold knife and a purse string is created with a 2-0 Prolene suture. A decent-sized end-to-end anastomosis (EEA) stapler device anvil is placed in the open end of the bowel, and the purse string is tied. Alternatively, an end-to-side anastomosis may be preformed depending on the lumen of the terminal ileum. The terminal ileum is returned to the abdominal cavity and the abdomen is re-insufflated. The first arm is re-docked and the anastomosis is performed after introducing the EEA stapler device through the anus. Prior to bowel anastomosis, we prefer to move the small bowel to the left of the aorta, make sure that the mesentery is not twisted, and ensure that there is no tension on the anastomosis.

Once the first arm is re-docked, the bowel is anastomosed under direct visualization. The anastomotic rings are inspected for integrity at a back table. A rigid proctosigmoidoscopy is performed on the operating table with normal saline to assess for anastomotic air leaks, integrity, and level. The robot remains draped until the surgeon's anastomotic assessment is complete. In the event of an air leak or dehiscence, the surgeon may easily address the situation via robotic suturing. The extraction site is closed in layers, including the peritoneal layers.

Conclusion

Multi-quadrant robotic colorectal procedures may be safely and effectively performed with platforms designed for single-quadrant access. With the aid of the anesthesia and operating room teams, the operating surgeon must ensure optimal patient positioning, robotic arm docking, and robotic platform placement from the start of the procedure. Effortless communication between the operating surgeon and assistant is imperative and must be ensured throughout the duration of the procedure. Sterility of the robot should be maintained until completion of the case in the event of further need of the device. While we advocate for the use of the robot in colorectal procedures, we believe that complex procedures, such as subtotal and total colectomies, should be performed after the operating surgeon has surpassed the robotic learning curve.

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Chapter 8
Robotic-Assisted Transanal Microscopic Surgery

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Introduction

This chapter will review the operative technique and advanced approach to perform a robotic transanal minimally invasive surgery (R-TAMIS) and a robotic transanal total mesorectal excision (R-TME). We will briefly describe indications and preoperative study, topics covered in the management of rectal cancer, and we will focus the chapter to outline the surgical technique and landmarks of R-TAMIS and R-TME.

Background

The classic transanal excision (TAE), used for lesions on the terminal third of the rectum, gave origin to transanal endoscopic microsurgery (TEM) which has become increasingly popular in the last few years. The TEM technique, originally described in the early 1980s by Buess [1, 2], is capable of providing high-quality local excision

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(LE) even on the proximal two thirds of the rectum [3]. Despite the good results that this technique has proven, its learning curve and the cost of the required devices have limited its expansion and broader use, secluding it to the most experienced hands in a few centers worldwide.

In 2009 the transanal minimally invasive surgery (TAMIS) technique was described [4]. This term encompasses many different acronyms in which the common denominator is the use of a single-port laparoscopic approach with transanal-standard laparoscopic material, adding a CO_2 insufflation and visual support with a laparoscopic camera [5].

The geometric design of the TAMIS port, primarily a shorter operating shaft compared to the TEM port [6], offers wider angulation and broader degree of movement, facilitating better dissection.

These advantages have made TAMIS the method of choice to access lesions of the distal/medium rectum, and they have also served as the basis for the development of new techniques such as the transanal total mesorectal excision (TME) [7–9]. However, this last technique is particularly demanding from a resources standpoint as it requires two highly trained surgeons, handling the laparoscopic camera and operating.

The evolution of laparoscopy, robotic surgery, has begun to take shape as an ideal alternative for these procedures. Its improved ergonomics reduce the technical struggles, minimizing the existing anatomical difficulties dealt with in rectal surgery. Furthermore, stable pneumorectum allows for a more precise dissection and resection with clear margins [10].

It was in the year 2012 when the first robotic TAMIS (R-TAMIS) was performed in a human [11], and some case series have been reported since with several differences between the techniques [11–15].

In this chapter we will illustrate a standardized way to perform a R-TAMIS.

Eligibility and Indications

Indications for R-TAMIS

Based on today's evidence, eligible lesions to be operated with R-TAMIS include: Tis, cT1N0 rectal cancer, unresectable lesions by colonoscopy, and submucosal tumors with positive resection margin in a previous endoscopic removal [11].

On the other hand, R-TAMIS should be avoided for large masses (>4 cm) that occupy more than 50–60 % of the circumference of the rectum, masses located 3 cm below the anal verge, and rectal cancer proven to invade the muscular layers by endorectal ultrasonography.

Indications for R-TAMIS-TME

The ideal patient would be a high BMI male presenting with a low rectal tumor.

It is indicated for tumors on the low and mid rectum eligible for a low anterior resection. High rectal tumors would be fair candidates for a partial mesorectal excision; however the use of a transanal approach compared to the conventional laparoscopy is still controversial.

It is not indicated for tumors invading the sphincters or T4 tumors that persist despite preoperative treatment.

The Role of Chemoradiation Therapy

Preoperative chemoradiation (PCRT) is recommended for patients with biopsy-proven adenocarcinoma clinically staged II or III. Nowadays, the international consensus gathered [16] still defends the use of fluoropyrimidine plus radiation [17, 18] although many clinical trials have worked with different therapies. A number of alternatives about the type, length, and dose of the PCRT treatment are still being studied.

Even the ideal timing for surgery after PCRT is also on debate. Nevertheless, most groups choose to perform the surgery around 2 months, but our current protocol includes surgery at 8 weeks post surgery after the last PCRT session.

If a total regression of the tumor is achieved [19], a full thickness excision of the previous tumor bed can be performed. Currently, some clinical trials are measuring the rate of recurrence comparing patients receiving this excision with those not receiving it who are on strict follow-up every 3–4 months. R-TAMIS-TME is recommended for T2 and T3 Nx tumors if total tumor regression is not achieved.

Preoperative Study

For presurgical assessment, every case should include on the patient's study a complete blood cell count, liver function tests, and coagulation profiles.

From a colorectal standpoint, patients must have undergone complete colonoscopy including biopsy, thoracoabdominal computed tomography (CAT scan), rectal MRI, and endorectal ultrasonography (ERUS) for a clinical staging. If a complete colonoscopy is not feasible, a CT colonography is recommended [20]. A barium or gastrografin enema study is an alternative if the tomographical colonoscopy is not available.

Preoperative evaluation of urinary and fecal continence and sexual functionality are important to quantify and discuss with the patient possible postoperative changes.

Patients are recommended to receive preparation with two enemas the day and prophylactic antibiotic before the procedure. One must also discuss with the patient the possibility of full thickness resection and inability to close the defect requiring abdominal approach.

Positioning Robotic TAMIS

Just like with any other robotic-assisted surgery, repetition and standardization of steps are of great support in improving and becoming more efficient in these procedures. This training and experience is required from every member of the operating team. A highly skilled assistant helping at the bedside is advisable as support can be needed for small port complications like CO_2 leaks or in academic settings to educate or assist less-experienced trainees.

The patients should be under general anesthesia. There have been reports on TAMIS resections performed under only spinal anesthesia, but there is not sufficient evidence to support this approach for R-TAMIS as for now [21].

A urinary catheter for bladder drain is used to monitor urine output and prevent urinary retention. Drainage however is not a predictor of renal function or acute kidney injury [22, 23].

A digital examination previous to the definitive positioning of the patient should be performed to ensure the location of the tumor. The recommendation is to position the patient so that the tumor is in the lower area of the surgical field. Therefore, lithotomy position with the patient's legs held on "candy canes" is recommended for tumors on the half posterior wall of the rectum, and the prone "jackknife" position is recommended for tumors on the half anterior wall of the rectum. Lateral position is recommended for mid-lateral tumors. If the tumor is closer to the anterior or posterior rectum wall, the bed can be angled from the original lithotomy or jackknife position.

In any case, R-TAMIS allows for ergonomic tumor dissection wherever it is located on the colonic wall. This makes the robotic approach much accessible than an average TAMIS overcoming the problem of the patient positioning, should there be any. This chapter covers the description of the procedure using the third-generation robotic platform (Si) which is the one available in our institution.

The da Vinci© (Intuitive Surgical, Sunnyvale, CA) is docked in a parallel fashion next to the left hip (Fig. 8.1). The patient should be in Trendelenburg keeping a little lateral tilt. The bed should be tilted so that the tumor comes to the lower area on the surgical field before docking the robot. Doing it after may cause the table, patient, or legs to collide with the robotic structure.

Only three arms are used in these techniques, one for the camera and two to operate. The fourth arm should be positioned away from the surgical field to avoid collisions (Figs. 8.2, 8.3, and 8.4).

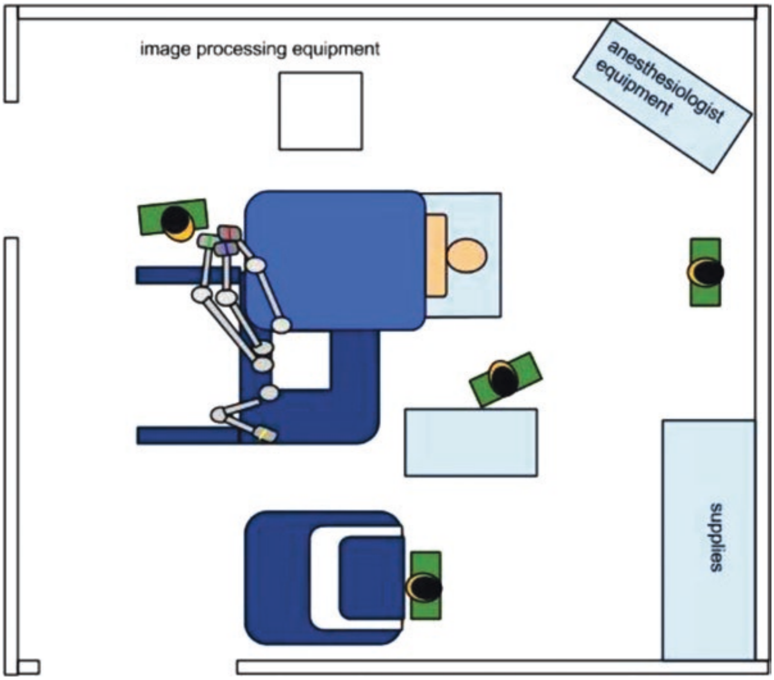

Fig. 8.1 Parallel docking

Fig. 8.2 Arm setup

Fig. 8.3 Port and arm setup

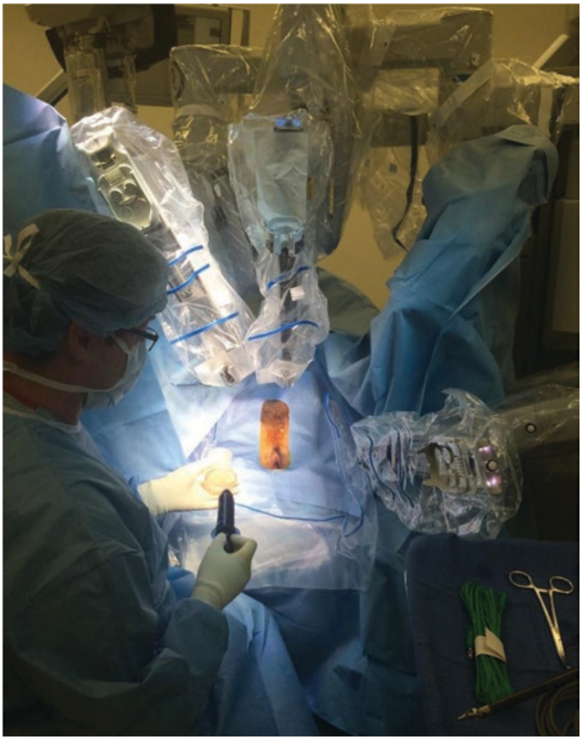

Fig. 8.4 Lateral placement arm #3

For R-TME all patients should be in the lithotomy position as this allows for both transanal and conventional laparoscopic approach. The bed should be angled right before docking the robot so the abdominal team will have a good access to the left pelvis.

Ports and Trocars

There is not a unique transanal access port. There are many different brands offered on the market today ranging from SILS© to GelPOINT©. Some studies have discussed the use of a latex glove covering an Alexis© laparoscopic system as a viable alternative. Anyhow, the ideal port would be one which provides a perfect pneumorectum and allows for broad movement of the robotic arms with minimal collisions of the trocars.

Before inserting the port, a gentle anal dilatation has to be performed. Fingers covered with profuse lubricant are used applying continuous and opposing pressure over the rectal sphincters symmetrically. Dilation devices may also be used if available.

An example is GelPOINT© path transanal access platform (Applied Medical, Rancho Santa Margarita, CA, USA). It consists of a rigid cylindrical sleeve, which helps protect against injury to the sphincter mechanism. After lubricating, it can be introduced into the anal canal using an obturator, but you may also grasp the distal part of it with a Kocher clamp through the sleeve orifice applying traction giving it a bullet shape easier to introduce. Once in position above the anorectal ring, the sleeve has to be sutured to the skin.

After inserting the transanal port, it is important to ensure proper fixation to avoid backward movements. The insufflation pressure recommended is between 12 and 15 mmHg. CO_2 leaks are also common, either from the port sides or from the trocars. An assistant should help avoid these leaks through the procedure. If AirSeal insufflation is available, this has been seen to be helpful in maintaining the view. If a GelPort is used, reinforcement with a transparent adhesive over its surface can be used to reduce CO_2 leaks or gel tears from trocar movement. This coating should be applied before the robotic ports are drilled into the GelPort. As the technique develops, so do the materials used, and in the future we should expect better ports to be out on the market.

In a regular R-TAMIS or R-TME surgery, three trocars are placed. Facing the surgical field, an 8 mm robotic trocar is placed at 12 o'clock (mid-superior), and two 8 mm robotic trocars will be placed accordingly at 4 and 8 o'clock (inferior-lateral) in a triangle fashion (Fig. 8.5). At least a 4 cm separation between the trocars must be achieved. A 30° angle-up camera will be used through the 8 mm trocar. Another extra 12 mm trocar can be placed at 6 o'clock (mid-inferior) for assistance. The other way to insert the trocars is through the trocars provided by the vendor which gives the robotic arms the best angulation outside of the surgical field and therefore less collisions.

For evacuation of smoke, a 5 mm laparoscopic suction-irrigation device can be used directly into the GelPOINT©, without the need for a trocar. Suction was operated by the bedside assistant. Again, AirSeal can keep area clear of smoke without the need for constant suction.

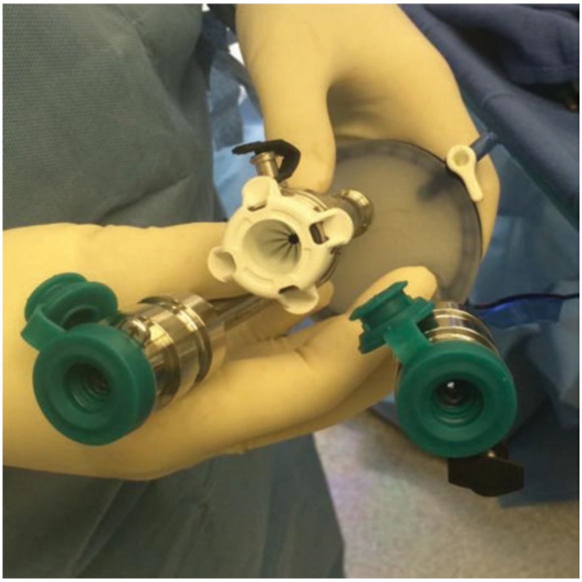

Fig. 8.5 Port placement

Operative Steps

TAMIS

To operate a Maryland grasper is placed on the robotic arm 1 (R1) and electrocautery in robotic arm 2 (R2).

The first step is to locate the tumor and mark its margins with electrocautery. Wide resection margins of 1 cm are recommended; however even margins as narrow as 5 mm have proven to be safe [24, 25].

Dissection should be initiated from proximal rectum advancing distally toward the anus. By doing it this way, we avoid creating defects greater than the marked resection limits. The depth of the dissection is also important. Given the curative intention of this procedure, a full thickness resection of the tumor is recommended. This also allows for more accurate pathology staging.

Now set needle drivers on R1 and R2. The needle can be placed in the field by opening the GelPort or through one of the trocars by the assistant.

Closure of the defect should be performed if possible. Just like dissection, closure should be performed from the proximal rectum to the anus. The use of barbed sutures can be useful [26]. Some authors however defend that defect closure is not needed [27].

The advantages of this robotic approach in such a confined space make this surgery technically less demanding and more precise and allow treating more than one lesion without the need to change the patient's position. Also, the assistant needs less training than the required when driving the laparoscopic camera.

Operative Steps TAMIS-TME (Transanal Stage)

This procedure is done in two surgical times, but it can be performed simultaneously by two surgical teams. Given how new this technique is a concurrent double robotic approach, very few reports are described in the literature, and standardization of this technique is not yet available.

The abdominal time consists of a low anterior resection of the sigmoid and the left hemicolon. Sometimes the splenic flexure of the colon also needs to be mobilized for a tension-free and better reach for the anastomosis. For the purpose of this chapter, however, we will focus on the transanal time.

For the transanal operation, we will place needle drivers on R1 and R2 at first. The next step is to locate the tumor; gauze can be used to push the tumor out of the surgical field but remember it will remain with the specimen.

Distal to the tumor a circumferential purse string is created. Thorough closure is very important to avoid future pressure losses of the pneumorectum. It is also necessary as fecal material may progress as a result of the colonic mobilization during the intra-abdominal phase of the surgery.

Once the circumferential suture is tied up, the new transanal surgical field is seen looking like a closed donut shape with a dot in the middle.

Needle holder from R1 is changed for an electrocautery and R2 to a Maryland grasper or dissector. Dissection will start around the middle dot on the pouch's center, but before, the circumference over which we will be working must be marked using the electrocautery 1 cm away around the dot. This way we reduce the risk to create corkscrew sections as a result of loosing references once the dissection has started.

For low rectal tumors, no dissection should be done less than 1 cm away from the dentate line. It is advisable to start dissecting posteriorly. The incision must be full thickness including muscular plane to enter the mesorectal plane. Pressure from the pneumorectum will help advance the dissection and show us the "holy plane" [28]. After the posterior mesorectal plane is opened, dissection is done anteriorly and lastly the lateral planes.

It is not advisable to go too deep in one single plane as it is done on conventional laparoscopy or the rectum will tend to retract. Uniform dissectional depth must be pursued throughout the whole circumference.

When dissecting the posterior rectal plane, going too deep may cause hemorrhagic complications from the sacral vascular plexus.

In male patients while dissecting the anterior plane, as usual, Denonvilliers' fascia must be respected. We should avoid entering the prostatic plane and damaging the seminal vesicles. In females special care must be put not to perforate the posterior wall of the vagina. An assistant can apply manual traction to the vagina to facilitate dissection. Usually this approach will let you see and dissect the structures much easier than the transabdominal classic one.

The lateral planes are the most complex; however, robotic maneuverability highly aids this process. If the mesorectal plane is not respected and dissection is done too deep, the hypogastric nerve plexus can be damaged.

Dissection is symmetrically continued until the peritoneal cavity is reached. If the abdominal team has already done the sigmoid and upper rectum mobilization, they would guide this final dissection from the peritoneal cavity. The intra-abdominal phase can also be performed robotically.

The robot can be docked out and the next part can be performed either hand or conventional laparoscopically assisted.

The specimen can be extracted either transanally or using the future ileostomy orifice if this will be necessary or performing a Pfannenstiel incision. If the specimen is taken out through an abdominal incision, it is recommended to use an Alexis wound retractor. It will protect the incision while the tumor is extracted allowing for effective pneumoperitoneum afterward.

Once the specimen is taken out, the device of choice may be used to allow proper anvil placement. It is important to make sure the anvil is correctly placed and that the anastomotic margins are free of adipose pedicles. This will facilitate a proper wall-to-wall anastomosis. It is our current practice to perform immunofluorescence of the proximal colon using 10 mg of indocyanine green to determine appropriate vascular flow.

Through the dilated rectum, we should create a new purse suture to close it distally. Then a circumferential stapling device is introduced. The use of stapler has been also described at this point. An end-to-end anastomosis is recommended, both EEA© 33 o 29, but also the use of the stapled hemorrhoidopexy device in the market has been described. In ultralow anastomosis, it is more advisable to perform a "J" pouch anastomosis or side-to-end anastomosis with a 3 cm remanent [29] stapling the distal colon. In this case, the anvil perforates the taeniae coli opposite to the mesorectum and it is fixed.

Under direct laparoscopic vision, the stapler is opened and the anastomosis is performed. At the time of stapling, avoid prying because it can cause mesorectal tears compromising the anastomosis. The integrity of the extracted anastomotic "donuts" must be checked.

We can perform a leak test filling the abdominal pelvis with saline and insufflating air into the rectum with a 50 cc needle. Some groups use a sigmoidoscope to directly check and insufflate the anastomosis.

Diverting loop ileostomy is recommended in high-risk cases like ultralow anastomosis, previous chemotherapy, chronic steroid use, or obese patients. Also, being male and smoker is associated with a higher risk for anastomotic failure [30].

Other Procedures

Other procedures for TAMIS approach have been described as alternative to treat urethrorectal fissures, Dieulafoy lesions or for foreign body extraction [31]. It is therefore to be expected that in these procedures R-TAMIS would bring all the advantages of robotic surgery to natural orifice surgery.

Summary

In conclusion, a robotic approach for transanal surgery, both R-TAMIS and R-TME, is a safe and feasible option if well planned. Practice and standardization of the docking steps are of vital importance to achieve competitive surgical times. The narrow anatomical space in which these procedures are performed represents a challenge. Robotic surgery offers better maneuverability allowing for easier and more precise dissection which constitutes a clear advantage on this surgical field. Also, the advanced ergonomics of robotic surgery are making it a better option for the surgeon.

The development and growth of robotic surgery as a strong alternative for conventional laparoscopy is a reality. Robotic surgery means for surgeons a substantial subjective improvement for intraoperative ergonomy, maneuverability, and precision, all exquisitely important in transanal surgery.

R-TAMIS	Difficulty level over 10
Review preoperatory tests	
Patient positioning	
Robot docking	
Material selection	
Mass identification	
Set resection limits	
Proper dissection	
Cierre del defecto	
Finish the intervention	

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Chapter 9
Surgical Immunofluorescence and Firefly Technology in Colon and Rectal Surgery

Elizabeth R. Raskin

> *The voyage of discovery is not in seeking new landscapes, but in having new eyes.*
>
> *Marcel Proust*

Introduction

Unaided by optical instruments, human vision is limited by the size, color, and luminosity of a target object, as well as the distance from that object. Surgical decision-making is inherently linked to the ability to clearly see anatomic structures and surgical planes and to subsequently manipulate them. Over the past century, surgeons have utilized technology ranging from the simplistic, nearly obsolete, head mirror to three-dimensional scopes and screens to overcome these visual limitations.

Innovations in the field of minimally invasive surgery (MIS) have been exponentially growing over the past 40 years in an attempt to improve surgeon dexterity, depth perception, and visual acuity. Robotic surgical technology has emerged to address some of the technical challenges posed by traditional laparoscopy, such as suboptimal optics, incongruous eye-hand coordination, and diminished instrument dexterity. The *da Vinci* Firefly Imaging System (Intuitive Surgical Inc.) expands the visual capacity of the robotic surgeon by employing immunofluorescent technology and thereby allowing for the illumination of anatomic structures that are invisible to the naked eye. Although a relatively new enhancement for MIS and the *da Vinci* surgical system, surgical immunofluorescence (IF) may give surgeons "new eyes" to more closely evaluate the vascularity of tissues and to enhance intraoperative decision-making.

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Immunofluorescence in Surgery

Fluorescence image-guided surgery (FIGS) is a surgical technique that involves the use of indicator substances that absorb and emit light under specific wavelengths to allow for visualization of particular anatomic structures. Methylene blue, quinine, fluorescein, and indocyanine green (ICG) are examples of indicator substances, or *fluorophores*, that have been used for medical and surgical purposes. The field of immunofluorescence is based upon the action of fluorophores binding to target molecules such as plasma proteins or antibodies, absorbing light and then emitting a specific wavelength of light once excited. FIGS has been utilized in various surgical fields, including ophthalmology; urology; cardiothoracic, hepatobiliary, plastic, and reconstructive surgery; and, more recently, colon and rectal surgery [1–6]. Cutting edge technology pairing near-infrared imaging (NIR) with intravenous administration of ICG has been utilized in open and minimally invasive colorectal surgery to evaluate blood supply and anastomotic perfusion [7–14].

History of Surgical Immunofluorescence

German physician and immunologist, Paul Ehrlich, is credited with the first in vivo use of fluorescence in 1882 when he intravenously injected uranin, the sodium salt of fluorescein, to follow the outflow of the aqueous humor of the eye. In the early 1900s, fluorescence microscopes were created by German physicists Otto Heimstadt and Heinrich Lehmann and allowed scientists to more closely evaluate the autofluorescence of bacteria, plants, and bioorganic substances such as albumin, elastin, and keratin. Quinine, a fluorophore found naturally in the bark of the South American cinchona tree, became an important compound to combat malaria in the Pacific theater during the World War II. Pharmacologists Bernard Brodie and Sidney Udenfriend (1943) developed a spectrophotofluorometer to evaluate the levels of quinine in the plasma of malaria patients, advancing the fields of immunofluorescence and targeted chemotherapy.

The first successful fluorescein angiogram in a human subject (1959) was performed by Indiana University medical students, Harold Novotny and David Alvis, and furthered the study of diabetic and hypertensive retinopathy. Another important fluorophore, indocyanine green (ICG), gained FDA approval in 1959 and soon found application in the assessment of ophthalmic circulation, cardiac output, and hepatic function and blood flow. Video fluorescence angiography utilizing fluorescein and ICG served as a precursor to FIGS as it allowed for real-time investigation of retinal and cardiac pathology and subsequent surgical interventions.

As video and digital technology advanced, FIGS expanded into such surgical fields as urology, hepatobiliary, plastic, and intestinal surgery. Fluorescence imaging has been reported in both open and minimally invasive surgery, with a developing subsector in the realm of robotic surgery [6, 8, 9, 11, 13].

Indocyanine Green (ICG)

Originally developed as a photographic dye, ICG has become the more utilized fluorophore for FIGS. It is a water-soluble, tricarbocyanine dye that absorbs light between 600 and 900 nm and emits fluorescence between 750 and 950 nm, with a peak spectral absorption at 800–810 nm in blood or plasma. When injected intravenously, ICG binds tightly to plasma proteins and remains exclusively in the vascular system. The affinity for the bloodstream allows for excellent evaluation of vascular anatomy and tissue perfusion. It is metabolized microsomally and solely excreted by the liver, with a half-life of approximately 3–4 min. The specific hepatic uptake and excretion also provide for enhanced visualization of the bile ducts. Although fluorescein has been similarly utilized in the past for assessment of intestinal perfusion, ICG is a more versatile agent given its short half-life, allowing for multiple administrations during a single operation [14].

The main applications of ICG fluorescence in general surgery have been visualization of vascular anatomy, assessment of anastomotic perfusion, examination of hepatobiliary anatomy, intraluminal tattooing, sentinel lymph node biopsying, and lymph node mapping [15–18].

ICG is a relatively safe imaging agent with very few reports of toxic or allergic reactions from its administration [19–21]. Rare cases of urticaria and anaphylaxis have been described [22]. Although ICG contains less than 5 % sodium iodide, caution should be exercised in patients with a history of an iodide or iodinated imaging agent allergy.

NIR Imaging Systems

Since 2005, several companies have manufactured biomedical NIR imaging systems (i.e., Stryker Corporation, Karl Storz GmbH, Olympus Corporation, Pulsion Medical Systems, Novadaq Technologies). All of the systems are designed around the capability of deep photon penetration of NIR light into tissues (<1 cm) to provide imaging of ICG, which emits light between 700 and 900 nm [23]. The systems are comprised of a spectrally resolved light source (i.e., LED or laser diode) which is focused on the surgical field that excites the fluorophore. The light emitted from ICG is then filtered and imaged onto a charge-coupled device camera (CCD). The images from the camera can then be displayed on the surgical monitor with or without the white light imaging background.

The *da Vinci* Firefly Imaging System

The *da Vinci* Firefly Imaging System was developed from Novadaq's SPY Imaging System technology to enhance visualization during robotic surgery. The Firefly platform is a fluorescence-capable high-definition (HD) vision system that allows for standard white light visible imaging, as well as NIR fluorescence (Firefly mode) imaging. After the injection of ICG, the system produces high-resolution, real-time NIR images that are displayed as a green overlay on a black and white image of the surgical field. Utilizing a NIR laser located in its endoscope (0° or 30°), Firefly enhances visualization of blood vessels, bile ducts, tissue perfusion, and blood flow. The images can be viewed on both the surgeon's three-dimensional stereo viewer and the external screen. This technology is standardly integrated into the Xi surgical robot model, however must be added to the Si model.

The surgeon can initiate Firefly mode with either the master finger switches while depressing the endoscope foot pedal or by toggling to "Firefly mode" in the settings section of the surgeon console. Alternatively, an assistant can switch to "Firefly mode" on the touchscreen of the vision cart. Ideally, Firefly mode is initiated immediately following the intravenous administration of ICG, producing a fluorescent image within 30–60 s. By manipulating the Firefly intensity slider on either the surgeon console or on the touchscreen of the vision cart, the intensity of the fluorescent image in relation to the black and white image can be adjusted.

Current MIS Colorectal IF Studies

The literature regarding the use of IF within the realm of minimally invasive colorectal surgery is growing. To best understand the application of IF for colorectal surgery with the robotic system, it is important to review the small body of literature involving IF and MIS for colorectal disease. To date, the focus of IF in colorectal surgery has largely been assessment of anastomotic perfusion and identification of vascular anatomy, with the goal of minimizing anastomotic complications.

Anastomotic leak (AL) can be a catastrophic complication following colorectal resection. Reports in the literature suggest that AL occurs in 1–3 % of ileocolic anastomoses and up to 10–20 % of colorectal anastomoses [24, 25]. Morbidity, mortality, and local recurrence rates are significantly increased by postoperative AL in the setting of colorectal cancer [7, 26].

Typically considered multifactorial in origin, AL has been associated with poor tissue perfusion, anastomotic tension, distal anastomoses, preoperative radiation, corticosteroid use, male sex, and smoking [7, 27–29]. Historically, assessment of anastomotic tissue perfusion has been a subjective evaluation by the surgeon based on unreliable parameters, such as active bleeding at the edges of the distal and proximal bowel, discoloration of the serosa at the resection margins, and the presence of a palpable pulse in the mesentery. In a study evaluating AL in 191 colorectal resections, Karliczek et al. concluded that these subjective parameters lack the predictive accuracy to determine if AL will occur and encouraged more objective tools to assess perfusion, such as visible light spectroscopy to measure anastomotic tissue oxygenation [30, 31].

In a systematic review of 37 studies detailing intraoperative colorectal anastomotic assessment techniques and their effect on postoperative anastomotic complications, Nachiappan et al. found that a wide range of mechanical patency tests, endoscopic visualization techniques, and microperfusion evaluations has been utilized [32]. Laser Doppler flowmetry, tissue oxygen tension, visible and NIR O2 spectroscopy, narrow band imaging, LFA, and NIR angiography have all been evaluated in non-randomized controlled studies [33–35]. The authors concluded that microperfusion techniques utilizing autofluorescent dyes were promising techniques, given the ease of performing the studies and the sensitivity of the information gathered.

Laparoscopic Studies

Kudszus and colleagues performed the first clinical study utilizing laser fluorescence angiography (LFA) to evaluate tissue perfusion and its effect on the rate of colorectal anastomotic complications [7]. In a retrospective, case-matched study, 402 patients underwent either laparoscopic or conventional colorectal resection by experienced surgeons. Half of the patients received ICG (0.2–0.5 mg/kg) immediately following the construction of the anastomosis with subsequent LFA. The IC-View® system (Pulsion Medical Systems), comprised of a digital video camera with an attached laser ($\lambda = 780$ nm) and an infrared filter, was utilized. Tissue perfusion was deemed suboptimal in 13.9 % (28/201) of patients who underwent LFA, resulting in an immediate revision of the colorectal anastomosis. AL occurred in 7 (3.5 %) patients in the LFA group and 15 (7.5 %) patients in the control group. Revisional surgery was required to address AL in all 22 patients.

Subgroup analysis demonstrated that the use of LFA significantly reduced AL in patients older than 70, those with hand-sewn anastomoses, and those performed under elective conditions. The authors concluded that the use of LFA reduced the risk of anastomotic leakage and subsequently decreased hospital length of stay.

Sherwinter and colleagues utilized fluorescence imaging to prospectively evaluate perfusion of the colorectal anastomosis and surrounding mucosa in 20 patients who underwent laparoscopic low anterior resection (LAR) [9]. Upon completion of the anastomosis, 2.5 mg of ICG was administered intravenously, and then a laparoscope was introduced transanally through a custom-built trocar. The PINPOINT™ system (SPY Image, Novadaq, Ontario, Canada), comprised of a specialized high-definition laparoscopic camera, light source, and NIR filter, was used to create the ICG angiogram. Each anastomosis was assigned a fluorescence score (FS) based on the surgeon's impression of ICG uptake. The FS ranged from 1 to 5, with 1 representing no ICG uptake and 5 representing maximal ICG uptake. A mean distance of 11 cm (±3 cm) from the anal verge was noted for all anastomoses. Complete anastomotic rings were retrieved and a negative leak test was noted in all 20 patients.

Four abnormal angiograms were reported in three patients with hypofluorescence (FS 3) and one with patchy fluorescence (FS 2) of the colorectal mucosa. Interestingly, almost all of the cases demonstrated significantly decreased ICG uptake at the anastomotic staple line, despite normal appearing uptake in the proximal and distal segments of the bowel. In two of the four patients demonstrating FS 3, the surgeon had decided to perform a diverting loop ileostomy prior to LFA. Postoperative recovery was uneventful for these two patients and both underwent successful loop ileostomy reversal. The remaining two patients (FS 3 and FS 2) developed postoperative peri-anastomotic fluid collections that required conservative management with antibiotics. Although the ICG angiogram did not change the surgical plan in any of the 20 patients in the study, the findings suggest that LFA has the potential to intraoperatively identify areas of poor perfusion and prompt immediate surgical revision.

Dovetailing on this information, Ris et al. prospectively studied 30 consecutive patients undergoing elective laparoscopic colorectal resections (25 left colectomies/5 right colectomies) who received ICG angiograms with the Pinpoint™ system [12]. Following the administration of the imaging agent, a successful angiogram was possible in 29 patients, with one patient not demonstrating any fluorescence. On average, fluorescence was noted 35 (15–45) seconds after administration of ICG. Executing the ICG angiogram was deemed feasible, adding a mean time of 5 (3–9) minutes to the procedure. In all 29 successful angiograms, perfusion of the anastomosis was considered satisfactory and did not prompt any intraoperative revisions. The confidence imparted by the visualization of sufficient perfusion did allow surgeons to avoid creating three defunctioning stomas after low anterior resection. No postoperative leaks were noted in any of the 30 patients.

Robotic Studies

Jafari and colleagues first utilized the *da Vinci* Firefly system to examine the role of ICG-NIR technology in reducing the rate of AL after low anterior resection (LAR) for rectal cancer [8]. This early study was a retrospective case-controlled analysis that included 40 patients who underwent robotic LAR with and without ICG angiography. An ICG angiogram was performed in 16 patients (41 %). Under white light, the surgeons marked the optimal point of proximal transection of the bowel and followed by injecting 6–8 mg of ICG. Firefly mode was initiated and allowed the surgeon to reassess the transection point under NIR light.

Prior to creating the anastomosis, the proximal point of transection was revised in three patients (19 %). The transection point was revised in one patient from the control group after noting duskiness to the bowel under white light. The distal transection point was not revised in either group. Given the low median level of the colorectal anastomosis (3.5 cm in ICG-NIR group/5.5 cm in control group), diverting ileostomies were created in 75 % of the ICG-NIR group and 77 % of the control group.

Delayed AL was discovered in one patient (6 %) in the ICG-NIR group on postoperative day 46, when the patient presented with persistent rectal pain. A small presacral abscess was noted on CT and treated with transanal drainage. Four patients (18 %) in the control group developed postoperative AL, resulting in two reoperations (in undiverted patients) and two percutaneous drainage procedures (in diverted patients).

The authors concluded that ICG-NIR technology helped reduce AL rate by 12 % and recommended further studies to validate these conclusions.

Leapfrogging the paper by Jafari et al., a prospective, multicenter study was performed involving 40 patients who underwent robotic left-sided colorectal resections followed by ICG angiography via the Firefly system [13]. Replicating the process of marking the planned resection margin in white light, followed by reassessment after ICG injection with NIR light, eight descending colon and 32 sigmoid colon resections were performed. Following the fluorescence imaging, the proximal transection margin was altered in 40 % (16/40) of patients, while the distal transection margin was changed in one patient. In four of the 16 patients who underwent revision of the proximal transection margin, diminished perfusion of the bowel was not noted under white light. Diagnosed on postoperative days 15 and 40, AL subsequently developed in two patients (5 %), both of whom underwent a revision of the transection margin. This study demonstrates the feasibility of utilizing Firefly technology for perfusion assessment and highlights that a large majority of the transection margins were altered by the ICG angiogram findings.

PILLAR II

A multi-institutional study involving 11 centers, the Perfusion Assessment in Laparoscopic Left-Sided/Anterior Resection (PILLAR) II study, looked at the feasibility and safety of fluorescence angiography utilizing the PINPOINT™ system in both laparoscopic and robotic colon resections [11]. Of the 139 eligible patients, 44 % had diverticular disease, 25 % had rectal cancer, and 21 % had colon cancer. Eighty-six percent underwent laparoscopic resection, while 14 % underwent robotic resection.

The study design included evaluating bowel perfusion at two critical steps during the procedure. First, a "baseline image" was performed at the planned point of proximal transection of the bowel, marked with a clip or instrument while under white light. ICG was then administered (3.75–7.5 mg) and PINPOINT was utilized to evaluate the line of demarcation between the perfused and nonperfused portion of the bowel. The planned point of proximal transection was then deemed *inadequate*, *adequate*, or *optimal*, and the decision whether or not to alter this transection point was documented. The second evaluation occurred after the resection and anastomosis were created. Following a proctoscopic air leak test, a second bolus of ICG was given and the PINPOINT laparoscope was inserted transanally. Once again, the anastomosis was documented as *inadequate*, *adequate*, or *optimal*, and any changes to the surgical plan were recorded (i.e., revision of the anastomosis or creation of an unplanned ostomy).

Successful imaging was possible in 98.6 % of patients, with only two patients failing to produce fluorescent imaging due to equipment malfunction. Eleven patients (7.9 %) underwent a change in the surgical plan, with nine requiring a revision of the proximal transection point, one requiring a takedown and revision of the original anastomosis after transanal evaluation, and one requiring a defunctioning ileostomy after concerns for poor perfusion under both white light and NIR illumination.

Anastomotic leak occurred in two patients (1.4 %) who had both undergone low ligations of the inferior mesenteric artery without proximal diversion. Both patients were treated conservatively and resolved completely without subsequent intervention. This study, which involves both laparoscopic and robotic resections, highlights the usefulness of ICG-NIR technology in identifying areas of poor perfusion to allow the surgeon to immediately revise an anastomosis and potentially reduce AL rate.

Conclusion

Evidenced by the developing body of literature, IF technology has a relevant application in the field of colon and rectal surgery. Promising results have been demonstrated in multiple MIS IF studies that suggest that anastomotic leak rate may be reduced by utilizing NIR technology. Providing real-time visualization of tissue perfusion and vascular supply, NIR IF technology provides functional imaging information to the surgeon and may ultimately play a role in surgical decision-making. While studies are limited in the field of colon and rectal surgery, the *da Vinci* Firefly system, combined with the three-dimensional optics of the *da Vinci* surgical robot, improves the ability of the naked eye to identify previously invisible anatomic structures. The potential of the Firefly system in colon and rectal surgery is yet to be realized but lays in the hands of the robotic surgeon.

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Chapter 10
Surgery on Obese Patients

Eduardo Parra Davila and Carlos Hartmann Otero

Background

According to the World Health Organization classification, normal BMI ranges from 18.5 to 25 kg/m^2, overweight ranges from 25 to 30 kg/m^2, and obesity is classified as a BMI of 30 kg/m^2 or more.

Abdominal surgery in obesity can be a challenge in the perioperative period. The prevalence of this condition in North America has progressively increased in the last years, and it is now considered an epidemic with significant implications [1].

Obesity is associated with high rates of comorbidities, which can adversely affect surgical outcomes. It is often associated with abnormal cardiorespiratory, metabolic function, and hemostasis, which may predispose morbidity and mortality after surgery [2, 3]. To reduce these risks, it will be important to understand and address specific problems associated with obesity itself, both in the hospital and after discharge.

Between 1986 and 2000, the numbers of individuals with a BMI >30, 40, and 50 kg/m^2 are reported to have increased tremendously in the United States [1].

The safety of laparoscopic colectomy for morbidly obese patients has been discussed in the last years; however, it is feasible as expected. Morbidity and conversion rates are higher for morbidly obese patients [4].

The advantages of laparoscopic colorectal surgery include reduction of pain, early return of bowel function, better respiratory function, and quicker return to normal activities.

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Robotic surgery was approved for clinical use by the FDA in 2000 and has been applied to several surgical procedures in urology, cardiac surgery, and gynecology. Although robotic-assisted procedures for general surgery are becoming more frequent, it continues to raise concerns about its higher cost compared with laparoscopy.

Preoperative Assessment

Appropriate risk reduction strategies could take the form of a guideline or checklist of key points to be considered at each stage of the patient's journey (e.g., surgical outpatients, cardiovascular preoperative evaluation, anesthetic pre-assessment, inpatient admission, operating room, recovery area and discharge suite). The ideal scenario for the surgical treatment of the obese is having on the schedule a checklist with the participation of clinical specialists who can lead the patient to a safe surgery. The case selection, counseling, or referral for counseling should be done considering the patient's conditions, such as smoking cessation, preoperative dietary advice, thromboprophylaxis, and planning for postoperative care and discharge. Each hospital should have its own policy or protocol for the management of the morbidly obese patient. Each patient should be individually assessed for risk and the care and treatment should be consultant-led [5].

It has been thought that obese patients are associated with poor surgical outcomes and that they are more likely to exhibit comorbid medical conditions, particularly cardiovascular, metabolic, and respiratory diseases conferring an increased morbidity and early mortality rate compared to the general population.

Diabetes: The impact of diabetes in the surgical patient is significant. It has been identified as an independent risk factor for postoperative morbidity. Diabetic patients can spend up to 50 % more time in the hospital postoperatively compared with nondiabetic patients [6].

For the preoperative patient, the HbA1c is a more useful test as it evaluates the degree of hyperglycemia that red blood cells have been exposed to over the 120-day life span of the cell.

A study of 7310 patients (Lauruschkat et al.) for coronary artery bypass surgery found that patients with undiagnosed diabetes more frequently required resuscitation and re-intubation and that have had a higher perioperative mortality compared with nondiabetic patients and known diabetics [7].

Most diabetic oral medications can be taken up until the day before surgery and are held on the day of surgery when patients are fasting. Patients taking any oral medication for diabetes should have their blood glucose monitored both immediately before and after their surgery. If patients develop hyperglycemia when off their oral agents, supplemental insulin should be used to correct the elevated blood glucose. Most insulin-dependent diabetics rely on both short-acting and long-acting insulin to control their blood glucose levels.

Diabetic patients should be operated on as early in the morning as possible. The patient may present a metabolic decompensation state to remain fasting long time, creating a state of ketosis and oxidative stress. Also catecholamine and other counter regulatory hormones release and increase cytokines. The stress of surgery is an issue with glycemic control [8]. Systemic reaction to trauma seen in the surgery can worsen even more his metabolic decompensation; with surgery one additional risk factor is added.

Cardiovascular: The challenges for the clinician before surgery are to identify if the patient has an increased preoperative cardiovascular risk, carefully perform supplemental preoperative evaluations, and manage the preoperative risk. Three pathologies related to cardiovascular disease are present in obese patients: arterial hypertension, arrhythmias, and thromboembolic disease. The association between hypertension and obesity has been well established by several studies. The risk of developing hypertension is greater in younger individuals and increases with obesity. It decreases with weight loss likely due to a reduction in sympathetic nervous system activity and suppression of the renin–angiotensin system. Particularly in women, the risk of an adverse perioperative cardiac event is related to the degree of underlying cardiac heart disease, associated comorbidities, and the type of surgery undergone. Walsh et al. [9] investigated the incidence and clinical correlates of postoperative cardiac arrhythmias in patients undergoing elective large bowel resection and acute postoperative hypertension, which is one of the more devastating cardiovascular complications after surgery. The cardiologist who evaluates obese patients for cardiovascular disease and preoperative consultation should consider sleep-disordered breathing in obese patients who present polycythemia and who are habitual snorers or have nocturnal gasping and choking and have been witnessed having episodes of apnea and daytime sleepiness. The estimated data from the National Health and Nutrition Examination Survey III (NHANES III) points that white Caucasian 20–30 years of age with a BMI ≥ 45 kg/m^2 will lose 8 years of life and their male counterparts will lose 13 years [10].

Obtaining a thorough medical history and physical examination is mandatory to coordinate an operative plan. Specifically, comorbidities such as diabetes, obesity, smoking, and collagen vascular disease may critically affect the operative plan.

Pulmonary embolism is the leading cause of mortality in experienced bariatric surgery centers. Obesity is an independent risk factor for postoperative development of deep vein thrombosis (DVT). DVT is caused by decreased circulating antithrombin III and decreased fibrinolytic activity. The surgical team must identify patients who are at high risk of developing DVT.

DVT prophylaxis should be initiated before the induction of anesthesia. Low molecular weight heparin such as enoxaparin has been used for thromboembolism prophylaxis, and nowadays it is considered the gold standard in DVT prevention. Sequential compression devices applied during and after surgery for DVT prophylaxis become the auxiliary device to prevent clot formation in the legs.

The indications for further testing for perioperative cardiovascular morbidity in the general population according to the “revised cardiac risk index” include (1) emergency surgical procedures and major thoracic, abdominal, or vascular surgery, (2) past or present history of coronary heart disease, (3) history of congestive heart failure, (4) cerebrovascular disease, (5) diabetes, and (6) preoperative serum creatinine levels >2.0 mg/dL [11].

Pulmonary System: Hypoventilation and obstructive apnea were observed in patients with severe obesity. In very obese patients, symptoms are habitually nonspecific. Sleep apnea is the most important respiratory problem, with several studies confirming that obesity is a major risk factor for the development of this condition. Oxygen consumption and carbon dioxide production are more marked in obese patients. Excess body weight around the ribs and under the diaphragm and intra-abdominal organs reduce chest wall compliance. The difficulty to expand the chest and the increased oxygen demand causes significant pulmonary deficit characterized by alterations in the pulmonary volumes. There is a reduction in functional vital capacity, total lung volume, total capacity, and expiratory reserve volume, which is a typical rank of a restrictive pattern. They develop more atelectasis, which persists and even tends to increase after anesthesia. As a result of atelectasis, most patients will exhibit low arterial oxygen pressures after open gastric bypass surgery. Vital capacity and maximum voluntary ventilation is reduced. Obesity leads a series of respiratory changes affecting the volumes, compliance, and ventilation/perfusion ratio, causing in turn a permanent hypoxemia. This results in a substantial alteration in the functional respiratory capacity and total lung capacity. The expiratory reserve volume is also compromised by 35–60 % due to the obese abdomen shifting the diaphragm into the chest. Obese patients have increased inflammatory factors, elevated plasma fatty acid, and decreased antithrombin III, generating an important prothrombotic state leading to a predisposition for thromboembolic disease. The use of laparoscopic techniques has decreased the amount of postoperative pain the patients' experience, and as a result, respiratory complications are decreased.

Technical Considerations

Obesity has long been suggested as a risk factor for conversion to open surgery during laparoscopic colorectal resection. In obese patients, peritoneal cavity access may be more difficult, and there is suboptimal peritoneal distention, reducing vision and operating capacity for the surgeon (Fig. 10.1).

Obesity is associated with increased conversion rate, operating time, and postoperative morbidity of laparoscopic colorectal surgery but does not affect surgical safety or oncological security. Some authors expect that with the application of laparoscopic surgery in patients with cancer, the oncological results have improved outcomes. Balentine et al. [12] found fewer complications and rapid recovery in minimally invasive surgery than the open surgery in cancer patients and also more accurately lymph node resection and more technically demanding due to hindered exposure of the bowel, thickened mesentery with difficulty in dissection, mobilization, or ligation of the vessels. The total mesorectal excision (TME), now the standard technique for surgical treatment of rectal cancer, has led to a reduction in local recurrence rates. The relative inaccessibility of the rectum within the bony pelvis and the proximity of other major anatomic structures place particular technical challenges to surgeons. High BMI increases the technical difficulty of TME and can compromise the possibility of complete resection, resulting in poorer oncologic outcomes [13] (Fig. 10.2).

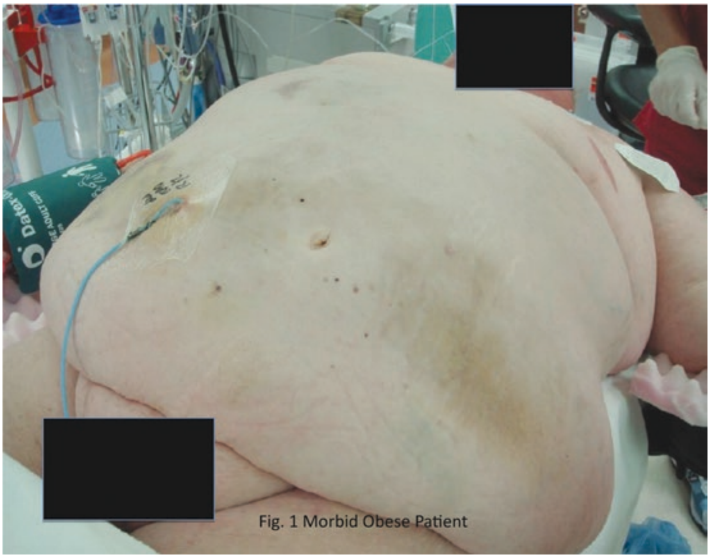
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Fig. 10.1 Morbidly obese patient

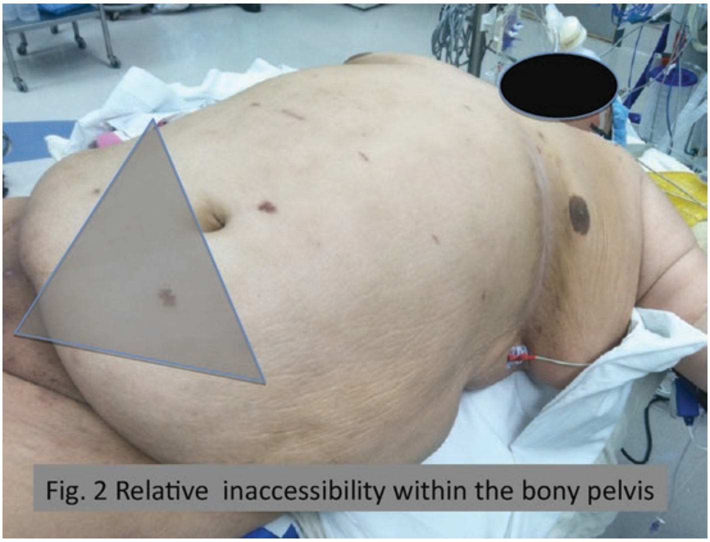
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Fig. 10.2 Relative inaccessibility within the bony pelvis

The da Vinci robot (Intuitive Surgical, Sunnyvale, CA, USA®) offers numerous advantages when compared to laparoscopy, including several degrees of motion, three-dimensional (3D) imaging, and superior ergonomics that enable easy and precise intracorporeal suturing. The improved visualization and tremor-less precision form the basis for the emergence of robotic techniques (Fig. 10.3).

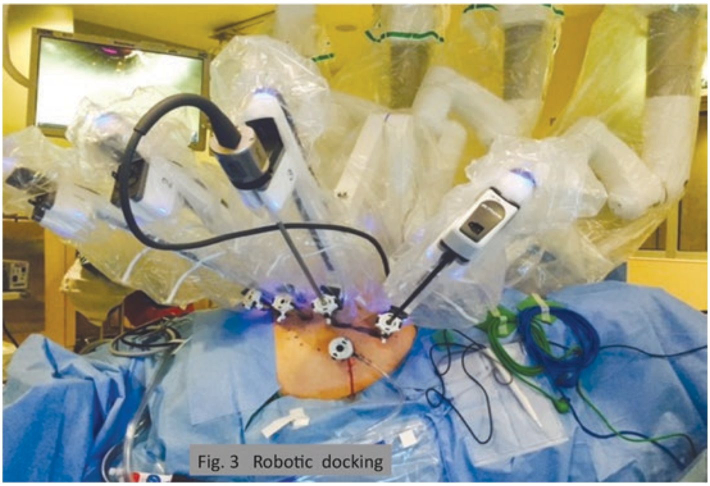


Fig. 10.3 Robotic docking

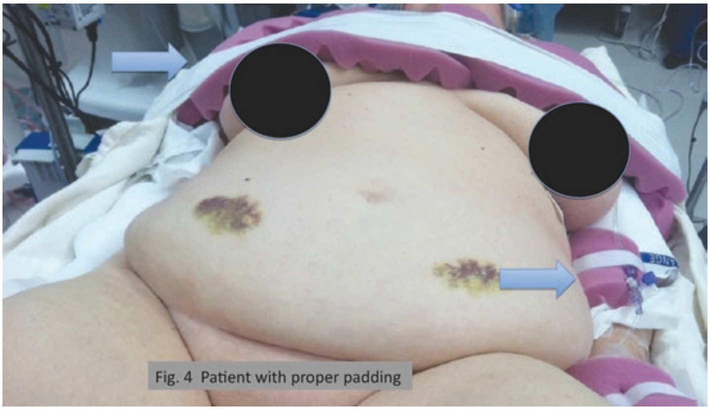


Fig. 10.4 Patient with proper padding

Positioning: Positioning is a challenge in obese patients; they are at higher risk for pressure sores and neural injuries depending on the position used for surgery. Placement is always necessary in these patients by limitation of intra-abdominal space needing a table that can accommodate the specific weight of the patient with proper padding, beanbag, and appropriate retrains over the chest and also sometimes adequate arm boards (Figs. 10.4 and 10.5).

Gaining Intraperitoneal Access: Gaining safe intra-abdominal access remains the first step in minimally invasive surgery. This can be made difficult in the morbidly obese and in multiply operated abdomen. Sites of previous operative intervention will certainly influence the strategy to gain initial access. Individual surgeons will need to judge their laparoscopic capabilities realistically in offering laparoscopic colorectal procedures to their morbidly obese patients.

Fig. 10.5 Bean bag and retrains

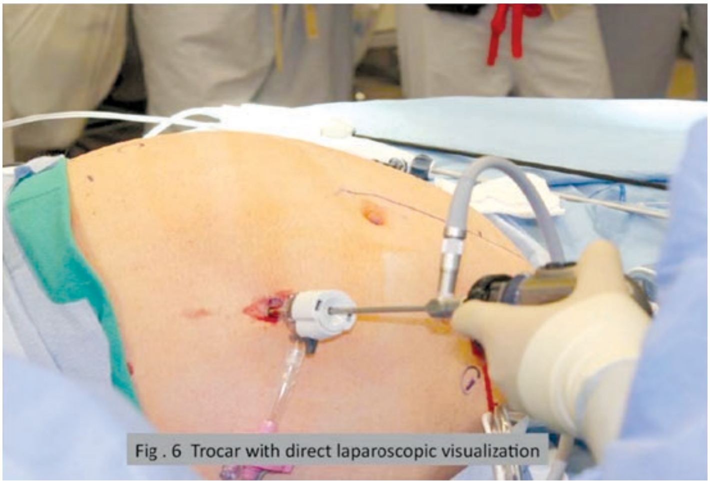


Fig. 10.6 Trocar with direct laparoscopic visualization

With proper preparation and careful consideration of surgical pitfalls of laparoscopy and robotics, the majority of the colorectal procedures that can be performed using a Veress needle or a trocar with direct laparoscopic visualization (Fig. 10.6) may be an easier approach, but traditional landmarks cannot be used in the morbidly obese patients. For extremely obese patients, longer trocars may be used, although these are rarely needed; for the robotic camera arm, the trocar should be 15 cm in length (Fig. 10.7). In these morbidly obese patients, the umbilicus is pulled downward. This means that some trocars need to be placed in the supraumbilical area. Leroy et al. analyzed 123 patients with laparoscopic left

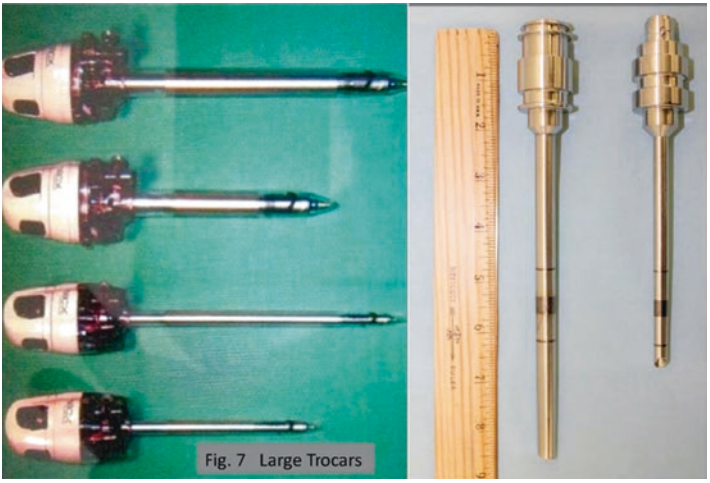


Fig. 10.7 Large trocars

Fig. 10.8 Umbilicus pulled downward

colectomy and reported that an increased number of ports were required in obese patients compared to non-obese patients.

Trocar Selection and Port Placement: Traditional landmarks cannot be used in the obese patient. For extremely obese patients, longer trocars may be used, although these are rarely needed. For the robotic camera arm, the trocar should be 15 cm in length. In these obese patients, the umbilicus is pulled downward. This means that some trocars are placed in the supraumbilical area (Fig. 10.8).

Fig. 10.9 In obese trocar position to reach the target

Incisions are placed 20–25 cm from the target, but in the obese, the distance should be confirmed and measured once the camera is inside the abdomen. Once the first port is placed under pneumoperitoneum, a minimum of 8–10 cm is measured between all trocars. Sometimes “cheating” on the trocar is necessary to be able to reach the target with minimal loss of the function of the robotic arm (Fig. 10.9).

If the patient is morbidly obese, the trocars are usually placed closer to the target anatomy. One example is the right colectomy where the ports tend to be closer to the umbilicus and midline in these obese patients, compared to their counterparts that are placed more laterally. This is because it is easier to go over the colonic flexures and able to see laterally straight down to the line of Toldt with the 30° down scopes.

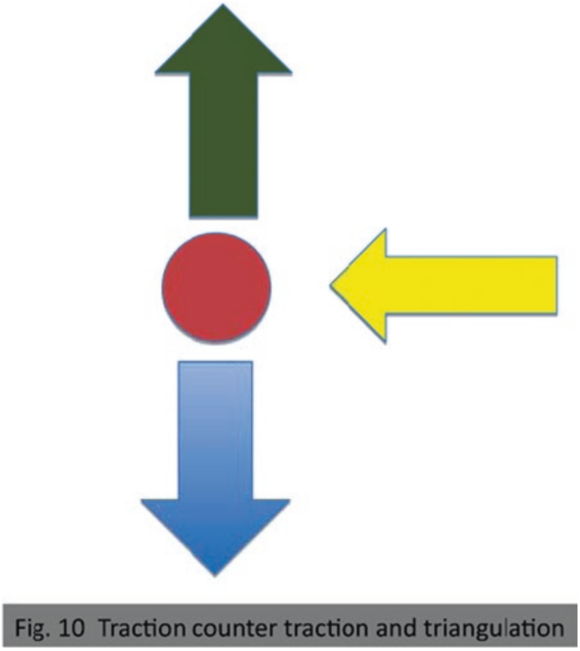
In 1974 Palmer [14] described a technique of putting a small trocar below the left costal margin for an abdominal entry. This author prefers to use this technique because in the subcostal region in the mid-clavicular line, the abdominal wall is thinner by the ribs exerting traction (Fig. 10.6), but the surgeon should do the technique that he or she is comfortable with.

There is much controversy over the number of trocars and where to place them. But the most important thing is to place the necessary trocars to improve the performance.

Important steps to identification of anatomy will be:

1. Traction, countertraction, and triangulation are the key for success (Fig. 10.10).
2. If mesentery is short, may start laterally gaining length on the mesentery elevation and then go medial for vessel control.
3. Make windows in the mesentery for vessel control enabling to use clips or staples on vessels.

Fig. 10.10 Traction countertraction and triangulation



4. May use ureteral illuminated stents for pelvic procedures. This will speed your procedure and also add safety against ureteral injuries. This is not the same as using illuminating stents.
5. If the patient has a colorectal lesion, it should be marked with tattoo in four quadrants to be able to identify easier the lesion, even when marked mesentery and omentum.
6. Mobilize the omentum to expose the colon and move the table to be able to gain exposure.
7. Rectal traction is performed cephalad by the assistant by using an umbilical tape placed around the bowel making this traction more effective and minimizing tearing the bowel specially when the colon is very heavy from the obesity.
8. Don't hesitate to place another assistant port if needed for suctioning while you traction with the other port or to improve the exposure.
9. In very difficult procedures if exposure is not adequate before conversion may use hand-assisted device to prevent a laparotomy if possible.
10. May use high flow insufflators or even sometimes two insufflators at the same time in super-morbid obese patients.
11. Narrow pelvis is frequently seen in males and if obesity is added, this becomes a challenge even for the expert surgeons. The robotic techniques allow a more control access due to the four arm exposure in the pelvis.
12. In robotic colorectal procedures exposed is performed by opposite traction of two arms and dissection for the third arm while placing the camera to be able to see the target anatomy and tall of them.

Postoperative Management

Complications are more common in the obese patient. Infections are increased almost twofold, and the odds of developing sepsis are significantly increased by 90 % [15]. To reduce these risks, it will be important to understand and remedy specific problems associated with obesity itself, both in the hospital and after discharge.

Obese patients should be treated in the postoperative period accurately and with the utilization of a checklist to avoid adverse outcomes.

The most common complications are infection of the surgical site and respiratory complications. Surgeons must take special care of obstructive sleep apnea. The use of positive pressure equipment is necessary to provide optimum levels of oxygen and thoracic expandability.

Surgical Site Infection (SSI): The reported prevalence of SSI is highly variable because of differences in SSI definitions, detection, and reporting. The reported incidence of SSI among colon and rectal procedures typically ranges from 25 to 45 %, depending partly on the respective institution's experience.

Procedures for diverticular disease, inflammatory bowel disease, and ostomy reversal incur the highest rates of SSI; gradually obesity is being identified as a risk factor for wound infection following colon and rectal surgery.

Khoury et al. [4] defined the impact of obesity on laparoscopic intestinal resection, including both colorectal and small bowel resection, with a case-matched study between obese and non-obese patients. Obese patients defined by a BMI >30 kg/m^2 experienced a significantly greater occurrence of wound infection (10.6 % vs. 4.8 %) even though intra-abdominal abscesses occurred with similar frequency [16]. In this same author (Khoury et al. in 2010), the morbidly obese patients had higher rates of wound infection, anastomotic leak, and abdominal abscess, as well as higher readmission and reoperation rates. In the last years, the literature has demonstrated a significantly lower tissue concentration of perioperative antibiotics in obese patients despite a twofold higher dose in comparison to normal-weight patients. Adipose tissue concentration of preoperative antibiotics remained below the minimum inhibitory concentration and was suggested as a potential mechanism for increased SSI among obese patients [17]. A large cohort study included 8415 colorectal operations of which 5291 (62.9 %) had a minimally invasive surgical approach. Overall, 25.6 % had no bowel preparation, 44.9 % had mechanical bowel preparation only, and 29.5 % received oral antibiotic bowel preparation. The SSI rate was 11.1 %, and it varied by preparation type: 14.9 % no preparation, 12.0 % in mechanical bowel preparation, and 6.5 % in oral antibiotic ($P<0.001$). Oral antibiotic bowel preparation group had significantly shorter hospital LOS: (median, 4; interquartile range, 3–6) versus other preparations (median LOS, 5) ($P<0.001$) [18].

Pulmonary System: Respiratory difficulties due to pressure on the diaphragm or due to an increase of intra-abdominal pressure predispose the presence of atelectasis, which is more frequent in the less mobile patient.

Pain management in these patients is a key point in the improvement. Breathing exercises and respiratory therapy help prevent respiratory complications such as pneumonia, which is an important cause of morbidity and mortality rates in the postoperative period in obese patients. It is desirable that the patient remains semi-sitting to improve intra-abdominal pressure during the immediate postoperative period, and oximetry must be used at least 24 h after the surgery.

Conclusion: More than two-thirds of adults are considered to be overweight or obese and more than one-third of adults are considered to be obese [19]; this condition is associated with high rates of comorbidities, which can adversely affect surgical outcomes.

Appropriate risk reduction strategies as a checklist and the participation of coordinate multispecialty clinical team who can lead the patient to a safe surgery, avoid complications and recovery success.

The advantages of laparoscopic colorectal surgery include reduction of pain, early return of bowel function, better respiratory function, and quicker return to normal activities and do not affect surgical safety or oncological security.

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Chapter 11
Robotics and Pelvic Floor

Nell Maloney-Patel, Juana Hutchinson-Colas, and Ashley Tsang

Introduction to Robotics for Repair of Pelvic Floor Disorders

Pelvic floor disorders can be categorized as primarily colorectal, gynecologic, or urologic. A multidisciplinary approach is often taken when there is a complex prolapse involving multiple organ systems [1]. Rectal prolapse, rectocele, enterocele, uterine prolapse, cystocele, and functional disorders of the pelvic floor muscles are all problems that can be treated surgically. Over a hundred operations have been described in the literature to repair pelvic organ prolapse. Generally, the operations can be divided into two broad categories, transabdominal and perineal. Evidence suggests that transabdominal procedures are more effective and applied to healthy patients while the perineal approach should be reserved for frail elderly patients with multiple comorbidities [2, 3].

Since the 1990s, major advances have been made in utilizing minimally invasive techniques in colorectal and gynecologic surgery with a majority of the abdominal

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approaches being performed laparoscopically within the last decade [4]. While laparoscopic surgery has been proven to offer patients faster recovery, similar rates of recurrence, shorter lengths of stay, and minimal complications when compared to open abdominal techniques [4–6], surgeons have found limitations that prevent them from widely adopting it into practice to repair pelvic floor disorders. Some of these limitations include the need for advanced laparoscopic skills, difficulty with visualization in the narrow pelvic space, loss of dexterity, and increased operative time. The introduction of robotic surgery has mitigated many of these difficulties as it allows enhanced visualization through high definition 3-dimensional imaging, greater reach and dexterity through advanced endoscopic instrumentation, and ergonomics through electronic translation of natural hand motions while a surgeon is able to sit comfortably during a complex case [4]. The *da Vinci Surgical Systems* by Intuitive Surgical are currently the only robotic surgery devices approved by the Federal Drug Administration. Robot-assisted laparoscopic surgery for pelvic organ prolapse is an excellent operation for surgeons learning to use the *da Vinci* systems as it provides a vivid and wide landscape of the pelvic anatomy.

Robot-Assisted Laparoscopic Surgery for Rectal Prolapse

Background

Delaney and colleagues performed the first cases of robot-assisted laparoscopic surgery for rectal prolapse at the Cleveland Clinic in 2001. While their operative time was longer for the robotic cases, they found they had similar complication rates and total hospital costs with shorter lengths of stay when compared to their conventional laparoscopic operations [7]. Heemskerk and colleagues in the Netherlands published the largest series to date in 2007 comparing operative time and costs in 14 patients who had undergone robot-assisted laparoscopic rectopexy to 19 cases of conventional laparoscopic rectopexy during the same time period by the same surgeons. The first 11 patients underwent a Wells rectopexy with mesh affixed to the anterolateral walls of the rectum, while the other 22 underwent a modified D'Hoore procedure with mesh affixed to the ventral aspect of the distal rectum. They found that robot-assisted laparoscopic rectopexy did not show more complications. However, the average operative time was 39 min longer and at greater cost [8]. Overall, robot-assisted rectopexy has been proven safe and feasible in the literature [7–10].

Preoperative Evaluation

Before operative intervention, a careful history, physical examination, and colonoscopy should be performed. There are three types of rectal prolapse: complete or full-thickness (procidentia) (Fig. 11.1), mucosal or partial thickness, and internal or intussusception of the rectum into the anal canal without protrusion [11].

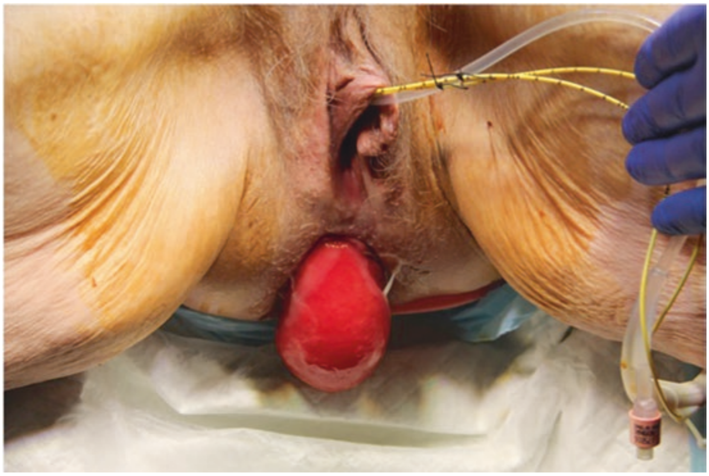


Fig. 11.1 Full thickness rectal prolapse

Patients often present with complaints of rectal prolapse or disordered gastrointestinal elimination, either constipation or fecal incontinence. They may describe protrusion of anorectal tissue past the anal verge, which may exist alone or in combination with symptoms of dysfunctional bowel elimination. Patients complaining of constipation symptoms often describe excessive or prolonged straining with bowel movements, pain with defecation, or incomplete evacuation of the rectum. A careful history and physical examination in addition to defecography is helpful in distinguishing obstructive defecation from slow-transit constipation. A Sitzmark study is useful in evaluating intestinal transit and will help to determine whether a partial or subtotal colectomy should be performed in conjunction with rectopexy. For patients who complain of involuntary loss of bowel contents, several diagnostic modalities are useful for evaluation. These include endoanal ultrasound and anorectal manometry. Endoanal ultrasound is the primary modality because it can accurately determine defects in the internal and external anal sphincter as well as anal canal length. Anorectal manometry measures resting and squeezing pressures of the anal canal and can also provide important information regarding anorectal innervation [12].

The diagnosis of rectal prolapse can sometimes be confused with prolapsed incarcerated internal hemorrhoids. This is distinguished by taking a careful history and examination. Prolapsed incarcerated hemorrhoids produce extreme pain and can be accompanied by fever and urinary retention, while rectal prolapse is easily reducible and often painless unless incarcerated. Careful inspection of the perineum with the patient in the sitting or squatting position is helpful for proper diagnosis. In the case that the prolapse is not seen on examination, defecography may aid in the diagnosis [11]. Of patients with rectal prolapse, a third experience urinary incontinence and 15 % have concurrent vaginal vault prolapse [13]. A dynamic colpocystoproctography (DCP) study or a dynamic MRI may assist in diagnosing other pelvic floor disorders involved. DCP has been shown to be a more sensitive test for diagnosing pelvic organ prolapse than physical examination alone and is useful for combined surgical planning. These patients require the collaboration of multiple surgical specialists [14].

Because this age group also has the highest incidence of colorectal cancer, colonoscopy or barium enema should precede an operation [11]. A neoplasm may form the lead point for a rectal intussusception. In the event a neoplasm is discovered, the medical and surgical treatment can change significantly.

Technical Considerations

Once rectal prolapse has been diagnosed, anterior resection with or without rectopexy, or rectopexy alone with or without mesh should be considered. Anterior resection involves resection of the sigmoid colon and proximal rectum with creation of a colorectal anastomosis. Resection rectopexy involves an anterior resection with suture fixation of the rectum to the sacrum (posterior) or Cooper's ligament (anterior). It is the preferred surgical option for patients with procidentia associated with chronic constipation, extensive diverticular disease, and excessive redundant sigmoid. Mesh is often used to help create fibrosis for pelvic support and to prevent recurrence, but only in cases of rectopexy alone. If a resection is considered, the bowel should be mechanically prepared with a polyethylene glycol or sodium phosphate solution. If a patient is unable to tolerate general anesthesia, a perineal approach should be considered which includes anal encirclement, mucosal resection, and perineal proctosigmoidectomy [15, 16].

Patient Positioning, Preparation, and Port Placement with the **da Vinci** *Si System*

After general endotracheal anesthesia is induced, the patient is placed supine in a modified lithotomy position with legs in adjustable stirrups and carefully secured to the table to avoid any shifting when adjusting the table. Bony prominences and pressure points are padded with both arms tucked, and the body position is secured with a vacuum-mattress device, especially laterally on the right side. A foley catheter is placed into the urinary bladder under sterile technique. An orogastric tube is placed by the anesthesiologist. The operative field is prepped and draped in standard fashion.

The abdominal cavity is entered through a 12 mm incision just 1 cm above the umbilicus using either the Hassan approach or Optiview with or without the Veress needle, whichever method is preferred by the surgeon. A camera port is inserted. The remote center or thick black band on the cannula must be at the level of the peritoneum. The abdomen is then insufflated. A 30° scope is introduced into the supraumbilical port and the peritoneal cavity is explored. A 13 mm port for the first instrument arm is then placed under direct visualization a minimum of 8 cm from the camera port, 1 cm medial to the mid-clavicular line (MCL), and along the spinoumbilical line (SUL). The distance to the symphysis pubis should be approximately 14–16 cm. If ileostomy is required, consider placing this port at the location of the area marked as the ostomy site. Under direct visualization, another 8 mm port for the second instrument arm is then placed a minimum of 8 cm from the camera port, 1 cm medial to the left MCL, and about 2 cm superior to the SUL. A third 8 mm port can be placed on the right or left flank to provide retraction and improve exposure. If planning to perform a resection rectopexy, a 15 mm port must be placed in the rightmost position to allow for the endoscopic stapling device. A 5 mm assistant port can be placed 8–10 cm cephalad to the first instrument arm and approximately 2 cm medial to the right MCL (Fig. 11.2). Of note, port placement and docking may vary based on patient body habitus. It is also dependent on the surgeon's comfort and skill level. There are hybrid and dual docking instructions available through the *da Vinci* Surgery Online Community website. Please refer to Fig. 11.3 for port placements according to body habitus.

The patient is then tilted right side down in deep Trendelenburg (Fig. 11.4). Laparoscopic technique should be used to sweep the bowel out of the pelvis for exposure. Next, the robot is docked on the patient's left side. The patient cart, camera arm, and endoscope port must be aligned crossing the anterior superior iliac spine. Standard robotic instrumentation includes an 8 mm or 12 mm camera, cautery hook for initial dissection, graspers, forceps, scissors, and vessel sealer.

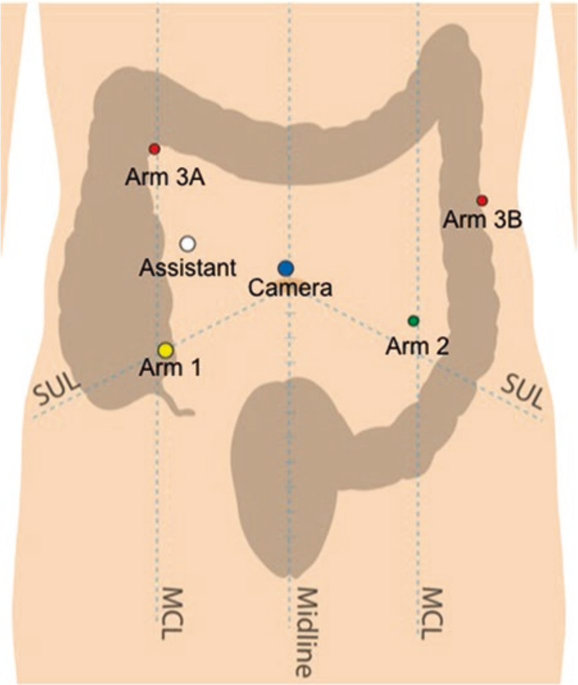
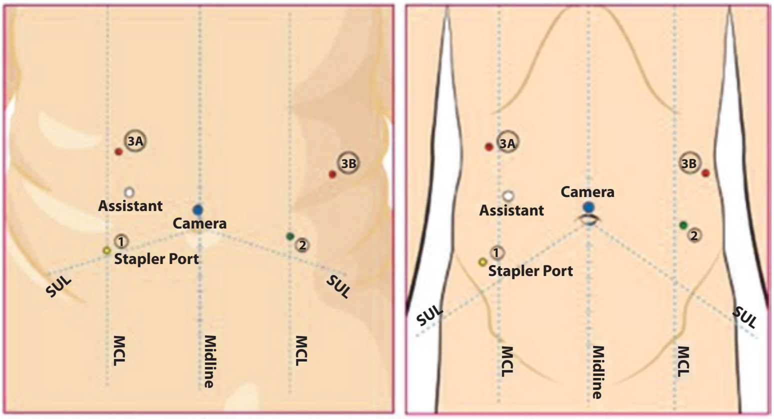
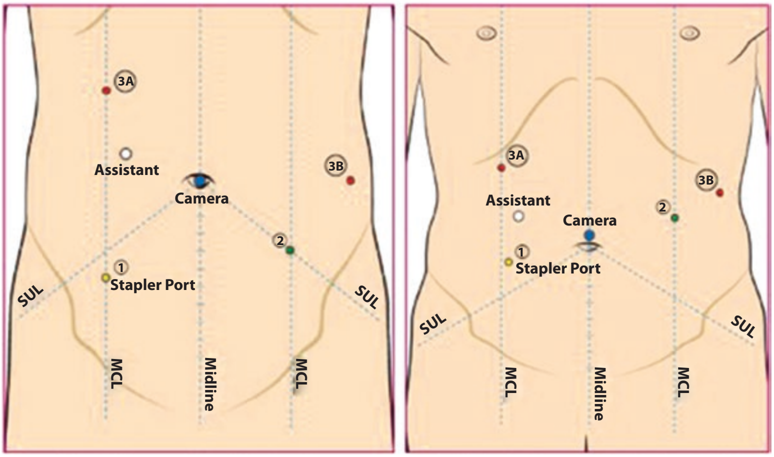


Fig. 11.2 Port placement for rectopexy using the *da Vinci* Si system



Suggested port placement for high BMI patients **Suggested port placement for low BMI patients**



Suggested port placement for tall patients **Suggested port placement for short patients**

Fig. 11.3 Port placements according to body habitus

Table 11.1 presents a list of recommended robotic instruments and accessories . Additional laparoscopic graspers as well as suctioning may be available to be used by the bedside assistant.

Patient Positioning, Preparation, and Port Placement with the da Vinci *Xi System*

Patient positioning and preparation is similar to that of the *da Vinci* Si System. The *da Vinci* Xi System follows universal port placement guidelines. In order to maximize workspace, ports must be placed in a straight line of at least 6–8 cm apart. They must be placed at least 2 cm away from bony prominences. The initial endoscope

Fig. 11.4 Patient positioning for robotic rectopexy

Table 11.1 Recommended list of instruments and accessories for robotic-assisted repair of rectal prolapse

Instruments	Accessories
Hot shears	Hot shears tip cover
Permanent cautery hook	Hem-o-lok medium large Clips
Fenestrated bipolar forceps	Hem-o-lok large clips
Double fenestrated grasper	2-0 Prolene CT or CT-1 needle
Small graptor (grasping retractor)	2-0 Prolene ST-70 needle
Cadiere forceps	
Large clip applier	
Large needle driver	
Laparoscopic graspers	
Laparoscopic forceps	
Laparoscopic sealing/division	

port must be inserted approximately 10–15 cm from the closest boundary of the target anatomy, and assistant ports must be placed at least 8 cm lateral to the adjacent ports, opposite of the patient cart. With the Xi System, the abdominal cavity is entered with assistance from the Veress needle. There is no Hassan available with this system. All ports are similar in size, except if requiring an endoscopic stapling device for colon resection, a 15 mm port must be placed. Therefore, the camera can be inserted into any of the ports.

For resection rectopexy, the initial endoscope port should be placed in the umbilicus or more superior and to the right if necessary. Using the universal port

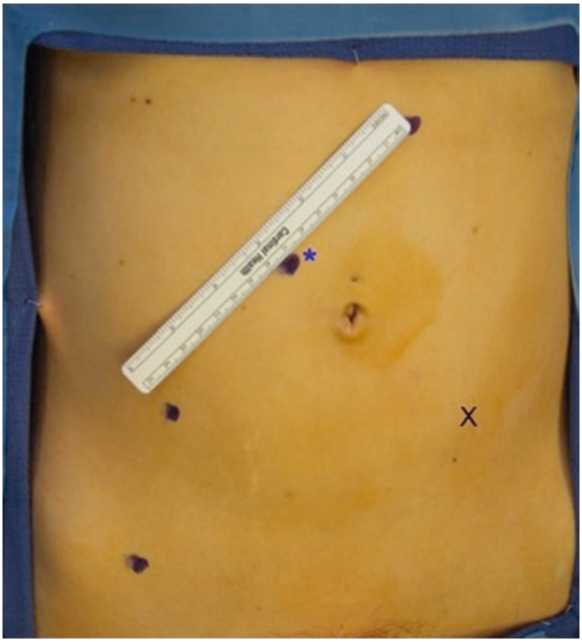


Fig. 11.5 Port placement for Xi system

placement guidelines for the Xi system, the remaining ports should be placed in a straight line following an imaginary line from the patient's left shoulder to the right hip as in Fig. 11.5. The system is then ready for deployment. Under anatomy selection, choose "Pelvic." The approach should be from the patient's left side. The operating room table should be placed as low as possible in Trendelenburg with right side down at or greater than 15°. The patient cart can then be driven to position the green laser crosshairs on the initial endoscope port. Adequate clearance must be ensured between the patient and the robotic arms. The arms should be flexed inward so that they are close together but not interfering with one another (Fig. 11.6). The boom should be centered above the initial endoscope. The arms should be docked according to the cart position. Arm 3 should be docked in the initial endoscope port if the patient cart is on the left, and Arm 2 should be docked in the initial endoscope port if the patient cart is on the right. The scope should be placed in the initial port and directed at the anatomy of interest for targeting.

Robot-Assisted Laparoscopic Rectopexy with Anterior Mesh Fixation

After proper patient positioning, port placement, and docking, the robotic instruments are introduced into the abdominal cavity via the ports. The lateral attachments of the sigmoid colon and rectum are incised with electrocautery. Dissection is carried down into the anterior space via Denonvilliers fascia to the rectovaginal space (Fig. 11.7a). Sometimes, a hernia sac that may be associated with an enterocele is

Fig. 11.6 Docking the *da Vinci* Xi system

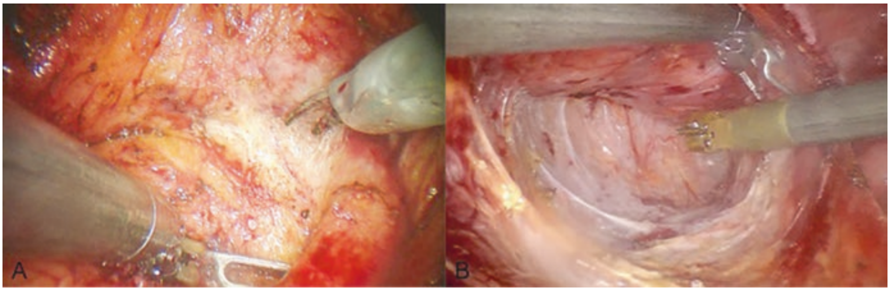


Fig. 11.7 Anterior and posterior dissection for resection rectopexy

seen here. The peritoneal sac may be resected. Posterior and lateral dissection is avoided. Once the anterior space is mobilized, a polypropylene mesh is secured around the anterior aspect of the rectum at the level of the peritoneal reflection and sutured bilaterally to the presacral fascia with nonabsorbable suture. The anterior wall of the rectum is thus pulled upward and posteriorly without traction. The posterior vaginal fornix can then be lifted and sutured to the mesh anteriorly, aiding in the repair of the rectocele as well as the prolapse [15–19].

Robot-Assisted Laparoscopic Rectopexy with Posterior Mesh Fixation

The patient setup is essentially the same as previously described, but the mesh is affixed to the posterior aspect of the rectal fascia propria and then to the presacral fascia with nonabsorbable sutures or endoscopic tacks. Dissection is started posteriorly.

The posterior pelvic plane under the superior rectal artery is entered. The left ureter and hypogastric nerve plexus are identified. Dissection is carried downward all the way to the pelvic floor below the rectosacral fascia (Fig. 11.7b). Sometimes to facilitate exposure, the right lateral stalk of the rectum is mobilized. Dissection then proceeds anteriorly into the rectovaginal plane to the upper limit of the vagina careful to preserve the left lateral ligament. The rectum is pulled cephalad out of the pelvis and where the fixation will occur is assessed. A window is made on the left side of the rectum to facilitate the rectopexy. A small rectangular piece of polypropylene mesh is inserted via the right lower quadrant port and placed down into the pelvic floor and extended superiorly to the mesorectum. The mesh is affixed to the sacral promontory with either endoscopic tacks or interrupted 0 nonabsorbable sutures approximately 5 cm on each side, a centimeter apart. The lateral stalks may then be sutured and tacked to the mesh to aid in suspension [15–19].

Robot-Assisted Laparoscopic Resection with Rectopexy

As previously described, after proper patient positioning, port placement, and docking, the robotic instruments are introduced into the abdominal cavity through the ports. Taking a medial-to-lateral approach, the redundant sigmoid is first lifted up, placing traction on the mesentery (Fig. 11.8). The mesorectum is then opened with an energy device just in front of the sacral promontory on the right and extended in both the cephalad and caudal directions. Careful dissection through the presacral avascular space is performed to preserve the hypogastric nerves anterior and inferior to the sacral promontory. Further dissection is carried out laterally along the mesentery, and the ureters, gonadal, and iliac vessels are identified and preserved. The sigmoid vascular pedicle is then isolated and divided (Fig. 11.9). Following this, the rectum is mobilized from its attachments down to the pelvic floor while maintaining the lateral stalks. The rectum must then be pulled upward from the pelvis and the distal resection margin defined for a planned anastomosis at the level of the sacral promontory. The upper rectum is then divided with an endoscopic stapling device. The proximal resection margin at the sigmoid colon is delineated, and the proximal sigmoid colon mobilized until it can reach the rectum. The robotic instruments are then removed from all the ports under direct visualization. The robot is undocked, and the gas is then exsufflated through the ports. A 5 cm extraction incision is made either through a Pfannenstiel incision or by widening the port incision in the left lower quadrant or umbilicus. Next, the proximal sigmoid is divided and an end-to-end anastomotic stapler anvil is placed within the lumen with either a purse-string device or running 2-0 prolene suture. A tension-free anastomosis is created at the level of the sacral promontory. An air leak test is then performed. Finally, rectopexy from the lateral stalks to the presacral fasia is performed with nonabsorbable sutures (Fig. 11.10). The pelvis is irrigated and hemostasis achieved prior to standard closure [16, 20].

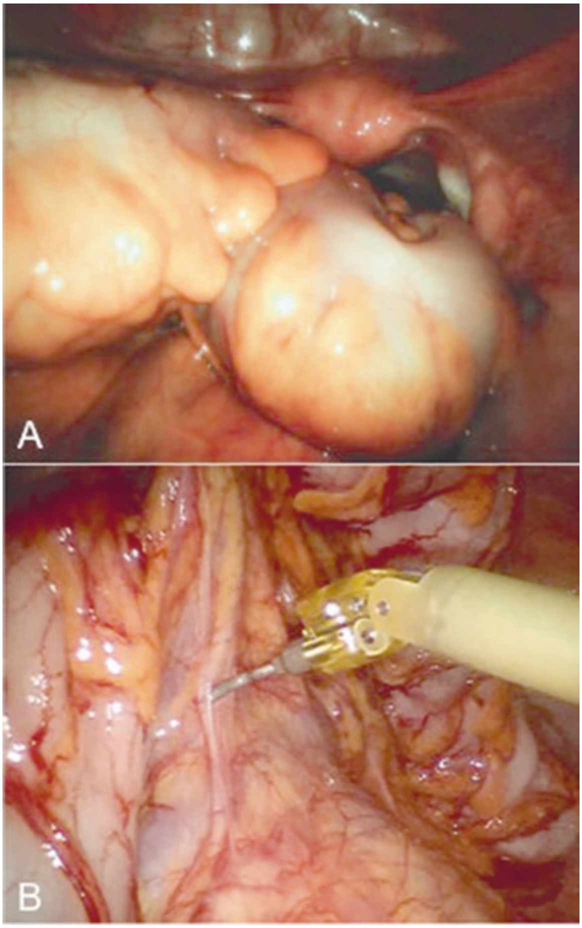


Fig. 11.8 Redundant sigmoid

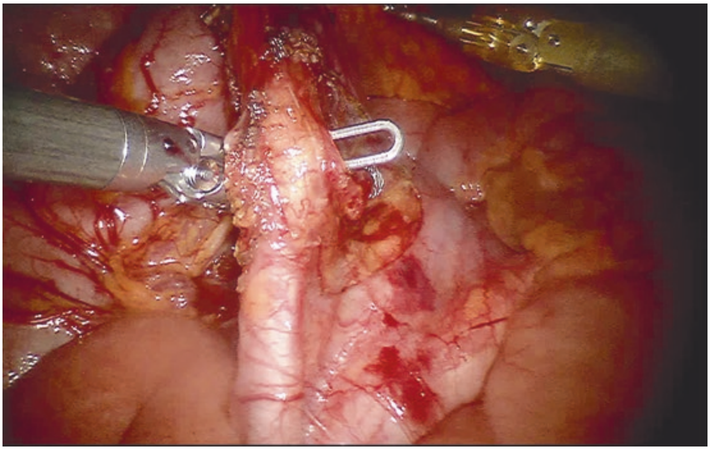


Fig. 11.9 Isolation of the vascular pedicle

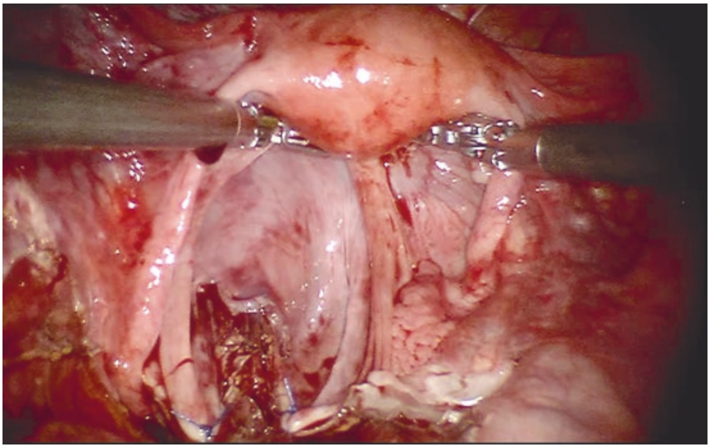


Fig. 11.10 Rectopexy

Complications

Intraoperative complications include hemorrhage and injury to the surrounding organs and structures such as the ureters, bladder, and vagina. General early postoperative complications include atelectasis, urinary tract infection, wound infection, deep venous thrombosis, pulmonary embolism, myocardial infarction and congestive heart failure, prolonged ileus, anastomotic leak, and deep pelvic infection. Late complications include anastomotic stricture, recurrence, bowel obstruction, incisional hernia, sexual and/or urinary dysfunction, and fecal incontinence secondary to autonomic nerve injury. Complication rates vary widely among institutions and depend on surgeon experience. The recurrence rate after robotic rectopexy has been reported to be anywhere between 0 and 23 %, depending on follow-up time. In all studies, operative time was longer, but minor complication rates similar to or less than that of the conventional laparoscopic approach. The majority of studies indicate that patient satisfaction and overall functional outcome were greater for those who underwent robotic rectopexy [21–24].

Robot-Assisted Laparoscopic Surgery for Uterine and/or Vaginal Vault Prolapse

Background

Transabdominal sacrocolpopexy with mesh is considered the standard surgical treatment for vaginal vault prolapse in healthy women with a cure rate of 85–100 % [6, 13]. Sacrocolpopexy suspends or lifts the vagina to the sacrum. Due to significant advances in minimally invasive surgery over the past two decades, many centers have been transitioning from the open transabdominal approach to conventional laparoscopy and now to robot-assisted laparoscopy [25–32].

Ayav and colleagues published the first case series of robot-assisted laparoscopic surgery for pelvic organ prolapse in 2005. They reported 12 of 18 patients with pelvic organ prolapse who underwent colpohysteropexies with mesh. The other six patients underwent either resection rectopexy or mesh rectopexy alone. There were no conversions to open or conventional laparoscopy, and they reported no operative or postoperative major complications [10]. The following year, Elliot and colleagues from the Mayo Clinic published a case series on 30 patients with posthysterectomy vaginal vault prolapse who underwent robot-assisted laparoscopic sacrocolpopexies with a minimum of 1-year follow-up. One case was converted to open due to hostile anatomy. All but one patient was discharged after an overnight stay. One had recurrent vaginal prolapse, and two patients developed vaginal mesh erosion. The mean operative time was 3.1 h. They reported a steep learning curve over the 2-year course of the study with the earlier cases taking 4.75 h and the later cases only taking 2.5 h [26].

Similarly, Akl and colleagues published the largest series of robot-assisted sacrocolpopexies, reporting on 80 cases over a 3-year period. Mean operative time was 197 min. Four cases were converted to open, three of which were due to limited visualization, and one to repair a bladder injury. Five patients (6.25 %) experienced vaginal mesh erosion, and one patient had a pelvic abscess. Three patients developed recurrent vaginal prolapse [9]. Overall, the majority of studies to date have concurred that robotic sacrocolpopexy is safe and feasible with a steep learning curve, producing similar results and lower morbidity when compared to conventional laparoscopy [9, 10, 25–32].

Preoperative Evaluation

As always, a thorough medical history and physical examination must be performed prior to surgical planning. Disorders of the pelvic floor involve multiple organ systems, and it is important to obtain a comprehensive review of systems. Patients with pelvic organ prolapse may complain of bulging or protrusion of the organs with or without symptoms of urinary or fecal incontinence, difficulty urinating, difficulty passing stool, or pelvic pressure. Figure 11.11 shows uterine prolapse with anterior and posterior vaginal vault components. On physical examination, their prolapse must then be graded according to a standard grading system, which includes the Baden Walker grading system [33], the International Continence Society (ICS) classification system, or the pelvic organ prolapse quantification (POP-Q) system. Pelvic floor muscle function tests may be performed for further assessment.

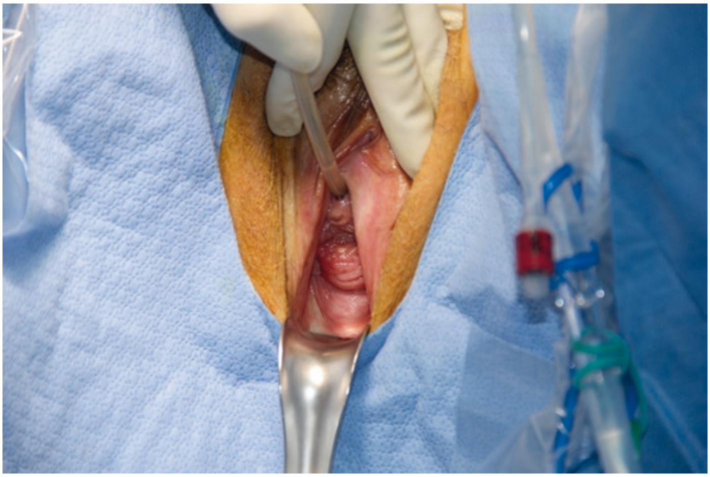


Fig. 11.11 Uterine prolapse with cystocele and enterocele

Technical Considerations

Total or supracervical hysterectomy with or without bilateral salpingectomy and with or without oophorectomy must be considered in women with pelvic organ prolapse. If a hysterectomy is planned, the level of resection must also be taken into consideration. If the patient has other uterine pathology, a total hysterectomy is often recommended. For patients with symptoms of urinary incontinence, an incontinence procedure must be considered. Mesh should not be used for sacrocolpopexy if a sigmoid resection is going to be performed. Cystoscopy is often performed at the end of the case to confirm the absence of bladder injury and ureteral patency.

Patient Positioning, Preparation, and Port Placement for the da Vinci *Si System*

The patient is placed supine on the operating table in a modified dorsal lithotomy position with adjustable stirrups. The patient's thighs should be roughly parallel to the floor when the table is level. All bony prominences and pressure points must be padded and the arms tucked, and the patient must be secured to the table to avoid shifting when placed in moderate to steep Trendelenburg.

The abdomen, upper thigh, vagina, and perineal areas are sterilely prepped and draped in standard fashion. A 16Fr Foley catheter is inserted for bladder drainage. If performing a hysterectomy prior to sacrocolpopexy for uterine prolapse, a uterine manipulator should be inserted. A colpotomy ring should be used if planning to perform a total hysterectomy. It should just cover the entire cervix and is useful in delineating the cervicovaginal junction. If performing a supracervical hysterectomy, the ring is not necessary. A pneumo-occluder balloon should also be placed in the vagina to maintain pneumoperitoneum if a colpotomy is performed at the time of total hysterectomy. This is also not necessary if performing a supracervical hysterectomy.

As in all cases, a camera port is inserted at or cephalad to the umbilicus. The abdomen is then insufflated, and the abdominal cavity surveyed with a 0° scope. In a 4-arm configuration, the first instrument arm port (8 mm cannula) is placed on the right, approximately 10 cm from the umbilicus and 30° inferior to the camera port. The second instrument arm port is placed on the left in alignment with the first arm port. The third instrument arm port is placed as far lateral to the left as possible, about 3 cm from the iliac crest and at least 10 cm from the second instrument port and at the level of the camera port. The assistant port can be placed just opposite of the third arm port on the right side. It is used to introduce suture and mesh as well as to facilitate removal of the uterus, if necessary. All instrument ports must be placed under direct vision with the 0° scope. At least 10 cm should be maintained between robotic ports and at least 6 cm between robotic and assistant ports. Please refer to Fig. 11.12a for port placement.

The patient should be placed in moderate to steep Trendelenburg as needed to retract small bowel and expose the sacrum. Adhesions should be taken down if necessary using laparoscopic technique. Once the anatomical landmarks are identified, the robot can be docked. Side docking or center docking can be used. However, if the surgery requires vaginal access, side docking is preferred (Fig. 11.13).

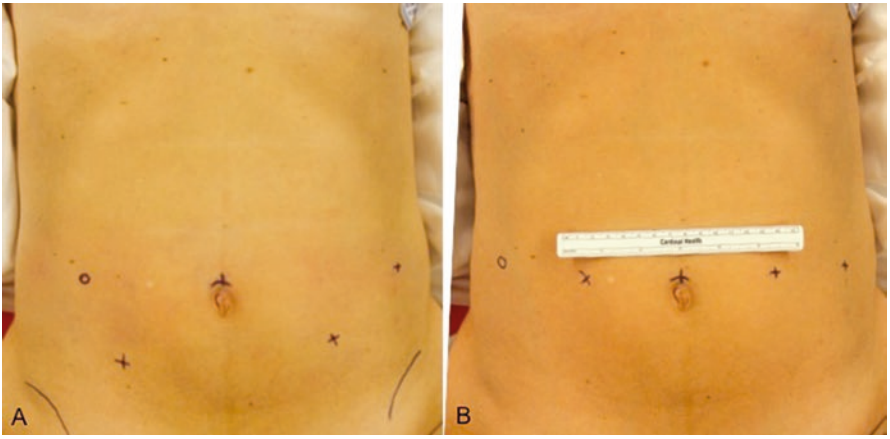


Fig. 11.12 Port placement for sacrocolpopexy using the Si and Xi systems

Fig. 11.13 Side docking for sacrocolpopexy

Patient Positioning, Preparation, and Port Placement for the da Vinci *Xi System*

Following the *da Vinci* Xi System universal port placement guidelines, again ports must be placed in a straight line at least 6–8 cm apart. They must be placed at least 2 cm away from bony prominences. The initial endoscope port must be inserted approximately 10–15 cm from the closest boundary of the target anatomy. For pelvic floor repair, the initial endoscope port should be placed in the umbilicus or more superior if necessary. The remaining ports should be placed laterally on both sides as in Fig. 11.12b. The assistant port can be placed in line with the other ports opposite the patient cart. The cart system is then deployed. Arm 3 should be docked in the initial endoscope port if the patient cart is on the left, and Arm 2 if the patient cart is on the right. The scope should be pointed at the midline of the pelvis, and the anatomy selected for targeting. The other arms are then ready to be docked.

Robot-Assisted Laparoscopic Hysterectomy, with or Without Bilateral Salpingo-oophorectomy, and Sacrocolpopexy

After patient preparation, port placement, and docking, the robotic instruments are introduced into the abdominal cavity through the ports. Instrument selection is up to surgeon preference. Table 11.1 refers to a list of standard instruments typically used

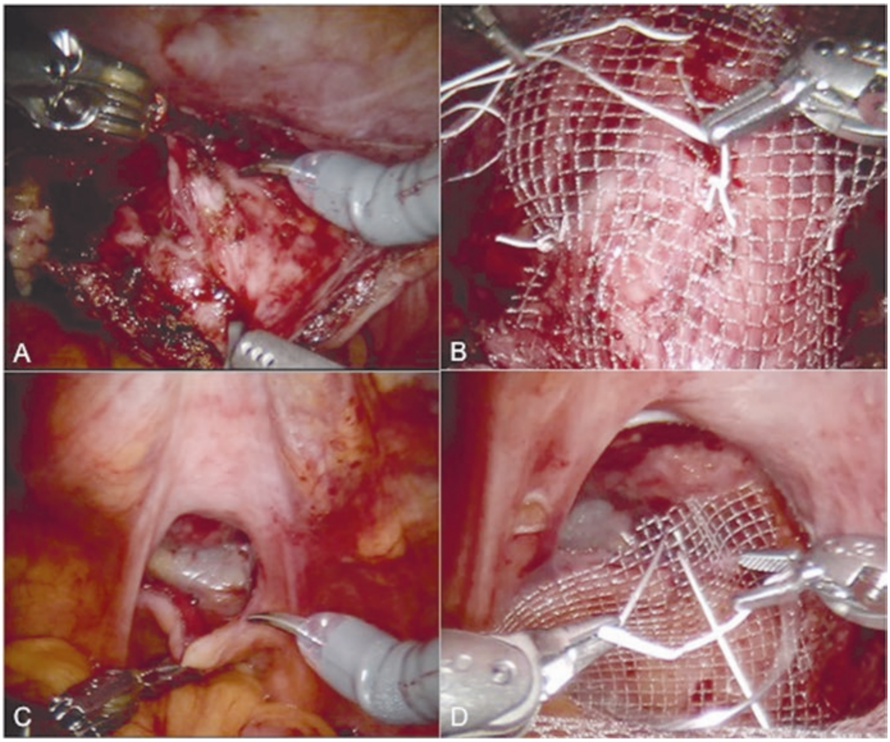


Fig. 11.14 Anterior and posterior vaginal wall dissection with mesh application (1)

for this operation. The uterus is identified and the overlying peritoneum is incised. The bladder is dissected away from the uterus and vaginal cuff. The assistant can help to control the uterus via the uterine manipulator. During this dissection, the broad ligament should be elevated off of the iliacs to prevent injury. The assistant can retract on the cornua to provide traction. Care is taken to avoid injury to the ureters. Once the uterocervical or cervicovaginal junction is identified, the uterus is excised and the cervical stump or the vaginal cuff is closed. The uterosacral ligaments are spared to maximize pelvic organ support. The uterus may be kept in the right or left paracolic gutter for the remainder of the case to be extracted later.

Next, the bladder flap is developed anteriorly within the avascular plane about 6–8 cm down the anterior vaginal wall to allow placement of the anterior mesh (Fig. 11.14a). Placing a rounded end-to-end anastomotic device into the vagina to manipulate the apex will help control the dissection. During this dissection, be sure to stay relatively close to the vaginal wall to avoid cystotomy, but take caution to avoid a vaginotomy as well since this will increase the risk of mesh erosion. Following this, the posterior vaginal wall should be dissected approximately 6–10 cm to allow for placement of the posterior mesh (Fig. 11.14c). Orienting the vaginal EEA anteriorly will help to expose the posterior vaginal wall.

The sacral promontory is then identified posterior to the sigmoid colon, and the overlying tissue dissected away (Fig. 11.15a). The sigmoid must be retracted laterally

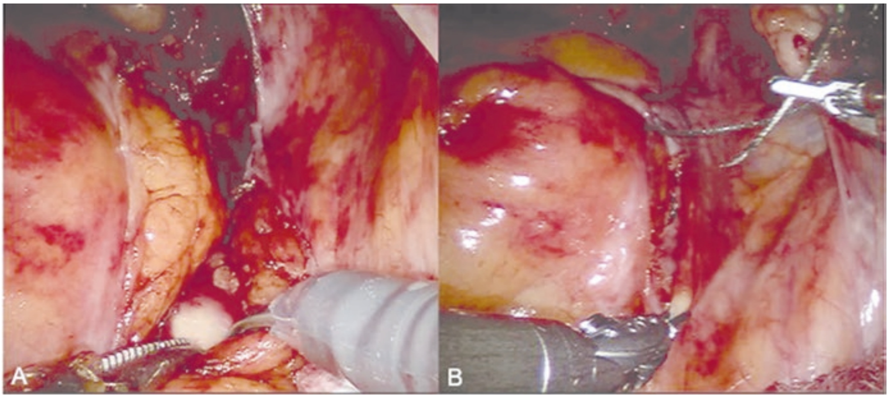


Fig. 11.15 Exposure of the sacral promontory

with an atraumatic grasper through the assistant port. The anterior longitudinal ligament should be identified early in the dissection. The presacral peritoneal dissection should be extended inferiorly to the vagina to help close over the mesh eventually. It is critical to remain oriented to the midline to avoid injury to the iliac vessels and ureters. Nonabsorbable monofilament or braided sutures may be preplaced in the anterior longitudinal ligament for eventual fixation to the mesh.

A polypropylene Y-shaped mesh is placed into the abdominal cavity through the assistant port and trimmed to a tension-free length. It should be oriented appropriately with the position of the posterior mesh in the cul-de-sac, and the anterior mesh should reach the full extent of the anterior dissection (Fig. 11.14b). The mesh is secured to the anterior vaginal wall with 6–8 sutures evenly distributed. The posterior mesh is then secured to the posterior vagina using 4–8 sutures (Fig. 11.14d). Avoid taking full thickness bites, of the vaginal wall during fixation as this will increase the risk of mesh erosion. The mesh should then be attached to the sacrum by suturing it to the anterior longitudinal ligament. Care is taken to avoid injury to the middle sacral vessels or the presacral venous plexus. Finally, the peritoneum is closed over the mesh with a running suture to help prevent small bowel obstruction (Fig. 11.15b). The uterus is then extracted in a specimen retrieval bag either by manual or power morcellation or intact via minilaparotomy or colpotomy. All ports are removed under direct visualization, and the incisions are closed in standard fashion. Cystoscopy is recommended at the end of the procedure to document the absence of bladder damage and ureteral patency.

Complications

In addition to the typical perioperative complications such as bleeding, thrombosis, infection, injury to the surrounding organs and structures, mesh erosion into the bladder or vagina is a late postoperative complication that occurs in 3–7.6 % of patients. It is reported to occur within the first 5–14 months after the procedure. Symptoms may include vaginal discharge or bleeding and dyspareunia. Partial or complete excision of the graft transvaginally is ultimately the best management, should mesh erosion occur [34, 35].

Multidisciplinary Robot-Assisted Laparoscopic Surgery for Pelvic Organ Prolapse

Nearly 30 % of all women and many men will develop a pelvic floor disorder in their lifetime. Many patients present with a combination of symptoms involving multiple systems. Because various pelvic floor issues often coexist, the need for pelvic floor programs and centers became obvious to many institutions. Our pelvic floor program is codirected by a colorectal surgeon and urogynecologist in collaboration with urology and physical therapy. Programs such as ours are dedicated specifically to restoring function in the pelvis. We review complex cases and after a thorough evaluation are able to formulate the best treatment plan that is specific to that patient. Often, a multimodality therapy is indicated, which includes behavioral changes, pelvic floor muscle strengthening, biofeedback, relaxation techniques, medications, and surgery.

Background

Today, as technology advances, so has collaborative surgical management of complex conditions in the same space. Laparoscopic sacrocolpopexy with concomitant rectopexy treats both the rectal and vaginal prolapses and can be facilitated by the use of the robot. The literature for combined open techniques supports collaborative surgery to treat multicompartment prolapse symptoms [36, 37]; however, the data for minimally invasive combined surgery is limited. In a retrospective cohort study, Unger and colleagues examined the peri- and postoperative outcomes for patients who underwent either a robotic sacrocolpopexy or conventional laparoscopic sacrocolpopexy with or without concomitant rectopexy. Of those undergoing concomitant rectopexy ($n = 36$), 8.6 % also had resection. Concomitant rectopexy was associated with a higher risk of transfusion (2.8 % [95 % CI, 0.5–14.2] vs. 0.3 % [95 % CI, 0.05–1.5]; $P = 0.04$), cardiac-related complications (5.6 % [95 % CI, 1.5–18.1] vs. 0.8 % [95 % CI, 0.3–2.4]; $P = 0.01$), pelvic/abdominal abscess formation (11.1 % [95 % CI, 4.4–25.3] vs. 0.8 % [95% CI, 0.3–2.4]; $P < 0.001$), and osteomyelitis (5.6 % [95 % CI, 1.5–18.1] vs. 0; $P < 0.001$). Interestingly, the two cases that had osteomyelitis did not undergo resection. There were no bladder, ureteral, or bowel injuries [38].

Preoperative Evaluation and Management

It cannot be overstated that a thorough history and physical examination must be performed on patients complaining of pelvic organ prolapse symptoms as it is often a multiorgan system disease requiring a multidisciplinary effort to help improve overall function and quality of life for them. At our center, patients with pelvic floor disorders will have a collaborative examination by both a urogynecologist and colorectal surgeon. We also enroll our patients in a 4-week biofeedback pelvic floor-training program offered through physical therapy prior to combined surgery. Biofeedback provides patients with the ability to recognize and exercise their pelvic floor muscles. Strengthening the muscles offers a more successful recovery after surgery.

Technical Considerations

As discussed earlier, consideration must be taken in regards to performing a concomitant sigmoid resection or subtotal colectomy with rectopexy, a total or supracervical hysterectomy with sacrocolpopexy, and/or an incontinence procedure depending on clinical diagnosis and symptomology. Generally, the use of mesh is not advised if performing a colon resection with rectopexy and sacrocolpopexy because of a high infection rate.

Robot-Assisted Laparoscopic Sacrocolpopexy with Concomitant Rectopexy, with or Without Resection

There are many different combined approaches that can be taken with a multidisciplinary team. Here, we provide a collaborative technique that has worked for our pelvic floor disorders team, which consists of urogynecologists and colorectal surgeons. For patient positioning, preparation and port placement using the *da Vinci Si* and *Xi Systems*, please refer to sections “Patient Positioning, Preparation, and Port Placement for the *da Vinci* Si System” and “Patient Positioning, Preparation, and Port Placement for the *da Vinci* Xi System”, respectively. Prior to docking, laparoscopic technique is used to survey the anatomy and sweep the bowel out of the pelvis for exposure. At our center, a dual console allows for both surgeons to simultaneously operate and assist each other within the same field. If we are planning to perform a bowel resection and primary anastomosis, we will often perform the resection first and leave the large bowel in discontinuity. Then the dissection for sacrocolpopexy with or without concomitant hysterectomy takes place as in section “Robot-Assisted Laparoscopic Hysterectomy, with or Without Bilateral Salpingo-oophorectomy, and Sacrocolpopexy”. The primary anastomosis and rectopexy is performed last since manipulation may compromise the integrity of the anastomosis and increase the leak rate. Mesh is avoided if a colon resection is performed.

Complications

As mentioned, there seems to be a higher risk of hemorrhage, infection, and cardiac-related injury associated with robot-assisted laparoscopic sacrocolpopexy with concomitant rectopexy with or without resection [38]. From our experience, robotic sacrocolpopexy with rectopexy is a feasible and safe procedure with minimal peri- and postoperative morbidity for the combined treatment of rectal and pelvic organ prolapse. Further studies are needed in order to adequately determine the positive and negative perioperative outcomes of a multidisciplinary surgical approach for pelvic organ prolapse.

Conclusion

Robotic surgery is an evolving technology with expanding applications. It offers patients the benefits of minimally invasive surgery such as nerve-sparing dissection, quicker recovery, minimal scarring, and less pain, while allowing surgeons to operate with improved optics, greater flexibility and precision, and less fatigue. Currently, a quarter of all adult women in the United States report one or more pelvic floor disorders. Over a third of them are under the age of 60 years old [39]. Due to the changing demographics in the country, it is projected that by 2050, 58.2 million women will have at least one pelvic floor disorder, with 41.3 million with urinary incontinence, 25.3 million with fecal incontinence, and 9.2 million with pelvic organ prolapse [40]. The growing prevalence of pelvic floor disorders over the next several decades will increase the demand for surgical repair, and therefore, surgeons must adapt to the evolving technological climate and arm themselves with skills in robotic surgery.

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Chapter 12
Robotic Surgery for the Treatment of Inflammatory Bowel Disease

Michelle DeLeon and Craig Rezac

Laparoscopic surgery was first introduced in the early 1980s in the field of gynecology. It quickly spread to general surgery and has become the mainstay of treatment for many surgical diseases. Prospective randomized controlled trials have illustrated the many benefits of laparoscopy over open surgery including shorter hospital stay and decreased postoperative pain [1]. Despite these well-established advantages, its incorporation into rectal surgery has been limited [2]. This is due to the steep learning curve and the difficult nature of laparoscopic dissection in the narrow pelvis.

The da Vinci robot was first applied to colorectal surgery in 2001, and since then has become increasingly utilized [3]. Several retrospective reviews looking at use of the robot in colorectal surgery have shown promising results including lower conversion rates and decreased postoperative complications [4]. It appears to be most advantageous for procedures requiring a low pelvic dissection, where traditional laparoscopy is very challenging. This chapter focuses on use of the robot in the surgical treatment of inflammatory bowel disease.

Inflammatory bowel disease is a term used to describe two specific clinical entities—ulcerative colitis (UC) and Crohn's disease (CD). These disease processes are differentiated based on clinical, radiologic, endoscopic, and pathologic data. However in some cases limited to the colon, a clear distinction cannot be made and these patients are categorized to have "indeterminate colitis." There is a drastic difference in the surgical treatment of ulcerative colitis and Crohn's disease, and so each will be discussed separately in this chapter.

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Ulcerative Colitis

Ulcerative colitis is characterized by inflammation of the colonic mucosa and submucosa that begins in the rectum and continuously extends through variable distances in the colon. The incidence is 1.2–20.3 cases per 100,000 persons per year and is more prevalent in developed countries [5]. It most commonly affects individuals between 20 and 30 years old, but there is also a small second peak during the sixth decade of life. The cause is unknown but it is thought to be due to a combination of genetic, immunologic, environmental, and dietary factors. Patients usually present with diarrhea, urgency, rectal bleeding, and abdominal discomfort. Diagnosis is made by endoscopic evaluation, where diffuse, continuous, and symmetric inflammation from the dentate line onward is seen [5].

Treatment begins with medical therapy. Over the past few years, the armamentarium of drugs available to treat ulcerative colitis has grown significantly. Aminosalicylates (5-ASA) are the most common medication used for the treatment of mild to moderate UC. Corticosteroids are highly effective in treating active flares, while immunomodulatory medications like 6 mercaptopurine and azathioprine are used for long-term treatment. They are beneficial for those patients who are refractory to therapy with 5-ASA alone and prevent the need for chronic steroid use [6]. More recently, biologic therapies against TNF-α have been utilized for the treatment of UC. Currently, there are three FDA approved medications for ulcerative colitis—infliximab, adalimubab, and golimumab. TNF-α is thought to play a pivotal role in the inflammatory cascade responsible for the mucosal inflammation seen in ulcerative colitis. These antagonists neutralize the biologic effects of TNF-α and have been shown to decrease the need for surgical intervention. In fact, a recent study by Targownik et al. showed that the 5-, 10-, and 20-year actuarial risk of colectomy in patients with UC is 7.5 %, 10.4 %, and 14.8 %, respectively [7]. This is in stark contrast to earlier studies reporting colectomy rates as high as 45 % at 20 years, before the advent and implementation of biologics and other immunomodulators [8]. Indications for surgery in patients with ulcerative colitis include massive bleeding, fulminant colitis with toxic megacolon, intractable disease, dysplasia, and carcinoma. Severe malnutrition resulting in growth retardation may require resection in a select group of patients, particularly in the pediatric population.

Unlike Crohn's disease, surgical treatment is curative for ulcerative colitis because it only affects the colon and rectum. Segmental resection is considered inadequate because of unacceptably high recurrence rates. Therefore, appropriate surgical options include total proctocolectomy with end ileostomy, restorative proctocolectomy with ileal anal pouch anastomosis (IPAA), and total proctocolectomy with a continent ileal reservoir (Kock pouch). Total proctocolectomy with end ileostomy has the advantage of removing all diseased mucosa, thus preventing any future recurrence of disease and progression to carcinoma. Major disadvantages are the need for permanent ileostomy and perineal wound complications. Total proctocolectomy with continent ileal reservoir was popularized by Dr. Kock in 1969, however fell out of favor because of the high complication rate and need for revision of the pouch in up to 50 % of patients [6].

Except in the emergent setting, restorative proctocolectomy with IPAA is the surgical treatment of choice for UC. It involves near total proctocolectomy with preservation of the sphincter complex. A single chambered pouch is created from the distal 30–40 cm of ileum. A double-stapled technique or rectal mucosectomy with hand-sewn anastomosis is performed to suture the pouch to the anus. The technique chosen for the pouch anastomosis is still somewhat controversial. The goal of mucosectomy is to eliminate all rectal mucosa up to the dentate line in order to prevent future recurrence and eliminate progression to cancer. However, this technique is more complex and challenging and may lead to increased sphincter damage and rates of incontinence [9]. Additionally, despite adequate mucosectomy, there have been reports of cancer occurring at the anastomosis [10]. Therefore, mucosectomy is generally preferred only in patients with multiple tumors or dysplastic lesions close to the rectum [9]. The double-stapled technique is technically less demanding and the residual rectal mucosa left may enhance sensation, leading to better functional results. However, disadvantages include risk of recurrent disease and progression to dysplasia or carcinoma in the retained rectal mucosa. Therefore, long-term cancer surveillance with pouchoscopy is needed. Several studies have shown no difference in pouch failure between the hand-sewn and double-stapled technique. However, a study done at Mayo clinic showed that those patients undergoing stapled technique had higher resting pressures and less nocturnal fecal incontinence, which may portend a better functional outcome in these patients [11].

The procedure is usually performed in two stages. The first includes total proctocolectomy, IPAA, and diverting loop ileostomy, followed by reversal of the ileostomy. In emergent cases, a three-stage approach is generally favored which includes subtotal colectomy, followed by completion proctectomy, IPAA, and diverting loop ileostomy, and finally reversal of the ileostomy.

There is little role for the use of minimally invasive techniques in the emergent setting. However, for elective procedures, studies have shown that laparoscopic restorative proctocolectomy with IPAA is equivalent to open IPAA with regards to safety and feasibility, and that laparoscopic IPAA is associated with shorter recovery times, earlier return to bowel function, less postoperative pain, and a better cosmetic result. Operative times, however, are longer for the laparoscopic approach compared to open [12]. Special consideration should be given to the role of laparoscopy and its effects on fertility and sexual function given the young age population seen in ulcerative colitis.

Previous studies have established that total proctocolectomy with IPAA has a negative impact on fecundity, with increased rates of infertility seen after this procedure [13]. This has a significant impact on the UC patient population where the average age for surgical intervention is during childbearing years. Studies show that the median age to surgery with proctocolectomy and IPAA in women is 27 years [14]. It is thought that the reduction in fecundity is due to adhesions to the fallopian tubes created at the time of surgery. Studies have shown that laparoscopic colorectal surgery results in less adhesion formation. Based on these results, laparoscopic proctocolectomy with IPAA should be associated with less pelvic adhesions and therefore, decreased rates of infertility. Recent studies have shown that this maybe the case, with Bartels et al. reporting increased pregnancy rates in those patients undergoing laparoscopic IPAA compared to open IPAA [14]. Therefore, a minimally invasive approach when possible should be strongly considered, especially in those women of childbearing age.

Sexual dysfunction after total proctocolectomy and IPAA for UC in men has been reported to be anywhere between 0 and 25 % [15]. Other studies have shown similar rates in women, and some have even reported that sexual dysfunction in women may be more adversely affected than in men [16]. These sexual disturbances are due to injury or disruption of the sympathetic and parasympathetic nerves during rectal dissection. In women, the proximity of the pouch to the vagina may have a significant role as well. At our institution, the percentage of patients reporting any sexual dysfunction postoperatively after total proctocolectomy with IPAA was 5.8 %. We hypothesize that this low rate is due to enhanced visualization achieved with the robot during the pelvic dissection, allowing for clear identification and preservation of the sacral nerves.

Despite the benefits that laparoscopy provides for patients undergoing total proctocolectomy with IPAA, only a small percentage of surgeons are performing rectal surgery laparoscopically, with rates as low as 10 % seen in the literature [2]. This is due to the technical challenges inherent in laparoscopy, especially in the narrow and deep pelvis. Factors attributing to this include a 2D picture, limiting fulcrum effect, restricted degrees of motion, unnatural positions causing surgeon fatigue and injury, and the steep learning curve. The da Vinci robotic system overcomes many of these hurdles by providing a 3D picture with the view magnified tenfold, allowing the surgeon to have complete control over the camera, providing seven degrees of freedom with instrument tips, filtering out physiologic tremor, and positioning for better ergonomics which ultimately reduces surgeon fatigue. These enhanced functions of the da Vinci robot enable easier rectal dissection in the narrow pelvis. Retrospective studies have shown a trend toward decreased conversion rates with the robot compared to laparoscopy [4]. At our institution, we report a conversion rate of 12.9 % for total proctocolectomies with IPAA. With the introduction of the da Vinci robotic system into colorectal surgery, we hope to see more total proctocolectomies with IPAA done minimally invasively in order for patients to reap the many benefits that minimally invasive surgery has to offer.

Surgical Technique

Total Proctocolectomy with IPAA: Complete Robotic Approach

A complete robotic approach is made possible with the new da Vinci Xi system. The new overhead boom allows the robotic arms to rotate as a group, which enables the surgeon to access all areas of the abdomen easily without having to physically redock the robotic base. The smaller, thinner arms allow movement to different quadrants of the patient with greater ease. Furthermore, the endoscope can be attached to any arm, allowing for better visualization when switching from different areas of the abdomen and pelvis.

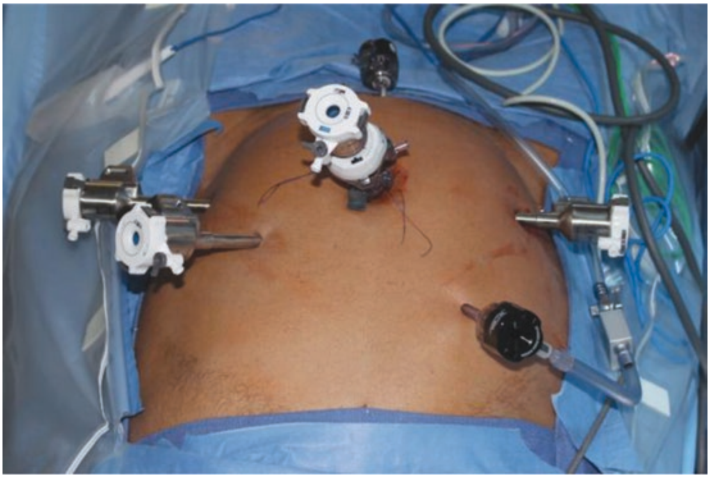

Fig. 12.1 Initial port set up. Patient's head oriented toward the *bottom* of the photo, patient's *left* to the *left* of photo

Fig. 12.2 Robot docked in the *left* lower quadrant

The patient is placed in the dorsal lithotomy position. Cystoscopy and placement of ureteral stents are routinely used for all total proctocolectomies. Three 8 mm ports, one 10 mm port, and a 5 mm assistant port are utilized (Fig. 12.1). The 10 mm suprapubic port is extended 4 cm and becomes the extraction site for the specimen. The robot is docked in the left lower quadrant. The configuration consists of a camera arm, three robotic arms for instruments, and the assistant port (Fig. 12.2).

The patient is placed in Trendelenburg position with the left side air-planed up. This gives maximal exposure to the descending and sigmoid colon and helps elevate the small bowel out of the pelvis. Once this is achieved laparoscopically, the robot is docked to the left of the patient. First, the lateral attachments of the rectosigmoid

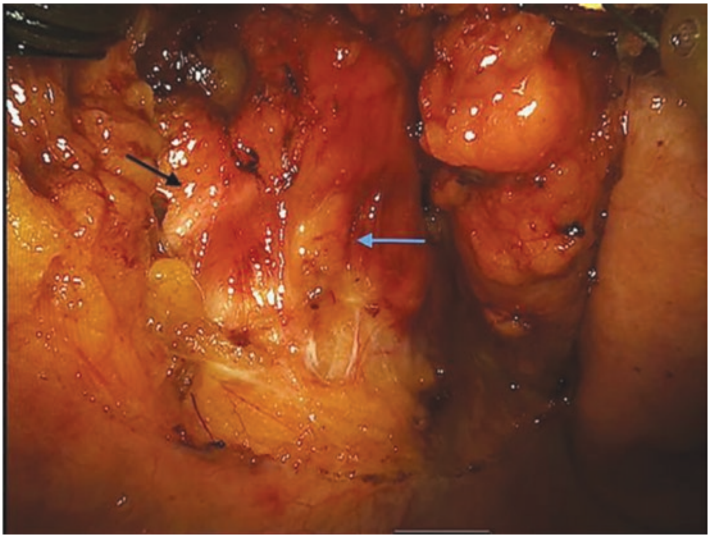

Fig. 12.3 Identification of the ureter (*black arrow*) and *left* common iliac (*blue arrow*) before dividing the inferior mesenteric artery

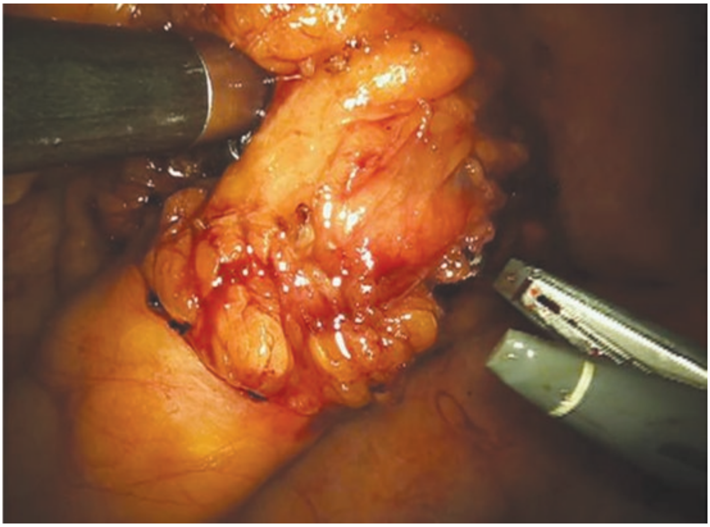

Fig. 12.4 Window created around inferior mesenteric artery that will be ligated with the robotic vessel sealer seen to the *right* of the photo

colon are taken down. This allows elevation of the sigmoid colon to identify the inferior mesenteric vascular bundle. Dissection then proceeds medial to lateral, underneath the inferior mesenteric artery (IMA), over the left common iliac, identifying the left ureter (Fig. 12.3). A window is made around the IMA and divided with the robotic vessel sealer device (Fig. 12.4). The dissection is continued until the peritoneal

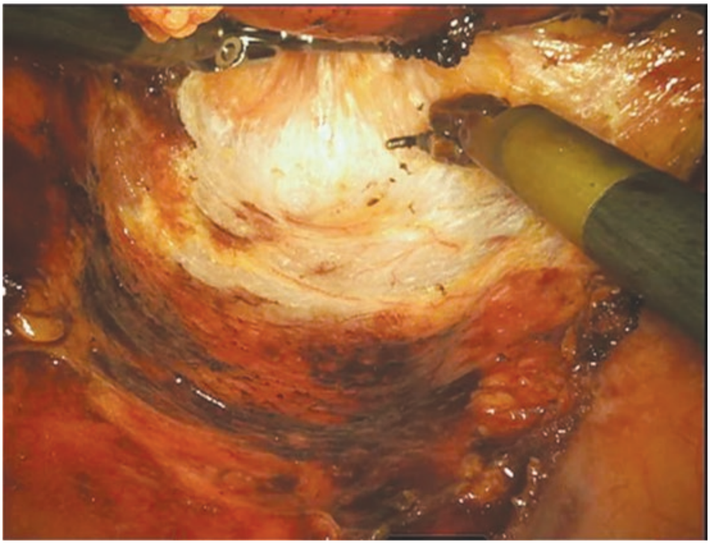

Fig. 12.5 Posterior TME dissection. The rectum is elevated to the *top* of the photo, while the hook cautery is used for the TME dissection

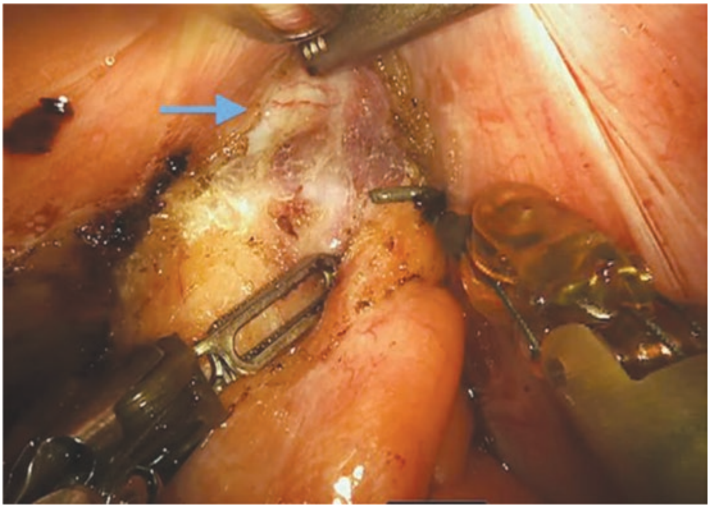

Fig. 12.6 Anterior rectal dissection. The *blue arrow* indicates the seminal vesicle seen while taking down the anterior peritoneal reflection. The rectum is retracted down and out of the pelvis for maximal exposure

reflection is taken down up to the splenic flexure. The pelvic dissection is then initiated, going posteriorly over the sacral promontory in a total mesorectal excision (TME) plane down to the tip of the coccyx (Fig. 12.5). The lateral stalks are divided. Lastly, the anterior peritoneal reflection is taken down, identifying the seminal vesicles (Fig. 12.6). A digital rectal exam is then performed to ensure that the dissection

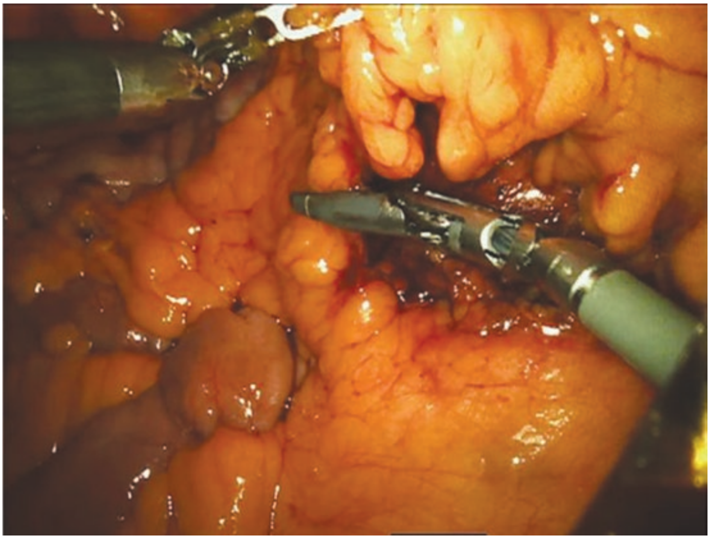

Fig. 12.7 The *left* mesocolon is divided with the robotic vessel sealer up to the splenic flexure

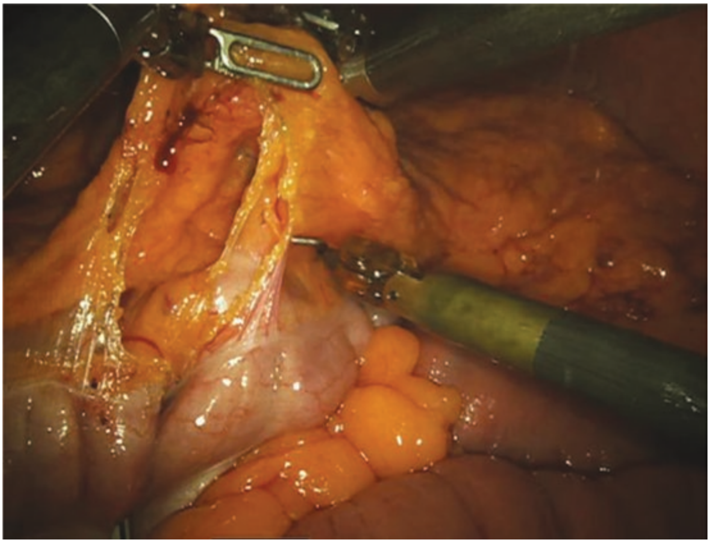

Fig. 12.8 The omentum is dissected off of the transverse colon with the robotic hook cautery to enter the lesser sac. The omentum is retracted toward the *top* of the photo and the transverse colon is *below*

is completed up to 1–2 cm above the dentate line. After this is confirmed, the robotic stapler is used to divide the distal rectum. The mesocolon is then taken with the robotic vessel sealer device up to the splenic flexure (Fig. 12.7). At this point, the robotic arms are undocked and repositioned to access the transverse colon.

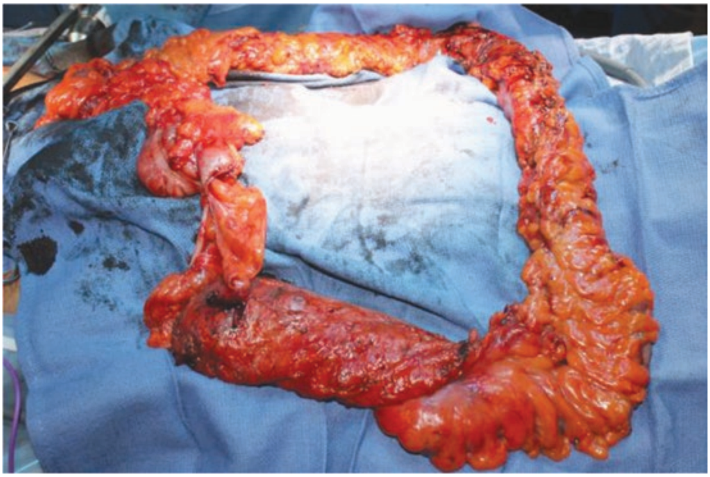

Fig. 12.9 Total proctocolectomy specimen

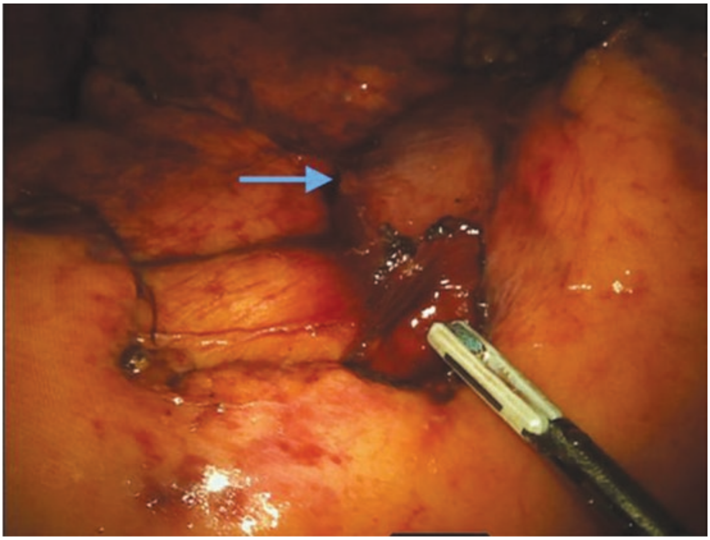

Fig. 12.10 Critical view of mesentery obtained before formation of J pouch to ensure the mesentery is properly aligned. Photo shows no small bowel to the *right* of the ileocolics. The *blue arrow* highlights the duodenum

The patient is then placed in reversed Trendelenburg and the splenic flexure is taken down. The omentum is dissected off of the transverse colon opening up the lesser sac (Fig.12.8). The mesentery of the transverse colon is divided with the robotic vessel sealer device going past the midline toward the ascending colon. The robotic arms are then undocked again and repositioned to access the ascending colon and hepatic

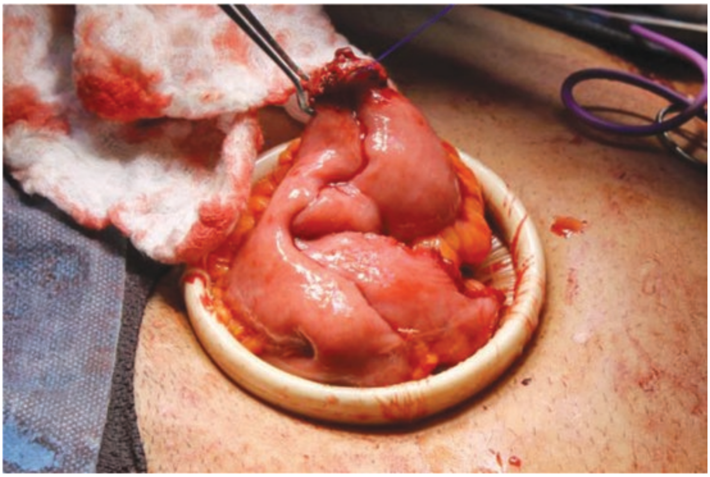

Fig. 12.11 Extracorporeal creation of J pouch using double-stapled technique

Fig. 12.12 Final incisions and ileostomy placement

flexure. At this point the patient is placed left side down for better exposure. The hepatic flexure and ascending colon are dissected off of the duodenum, being sure to identify the right ureter. The ileocolic vessel is then isolated. After the entire right colon is fully mobilized, the suprapubic port is opened approximately 4 cm and an Alexis wound retractor is placed. The entire specimen is delivered through this port site. A handheld LigaSure is used to divide the terminal branches of the ileocolic vessels flushed to the right colon. The terminal ileum is divided with a GIA stapler and the specimen is removed (Fig. 12.9). Before the terminal ileum is exteriorized to form the J pouch, the surgeon must make sure that the small bowel mesentery is not twisted. This is confirmed when the mesentery is configured so that ***only*** the duodenum and *no small bowel* is seen to the right of the ileocolics (Fig. 12.10). The terminal ileum is then prepared. Thirty cm of the distal ileum is folded on itself to make a pouch of 15 cm in length using the Echelon stapler (Fig. 12.11). An EEA stapler is then used to create the ileoanal anastomosis. Care is taken not to rotate the pouch and to ensure there is no tension on the anastomosis. A protective loop ileostomy is then created in the right lower quadrant (Fig. 12.12).

Total Proctocolectomy with IPAA: Laparoscopic, Robotic-Assisted Approach

In this technique, there is only one docking of the robotic arms, and it is used only for the rectal dissection. This method is preferred at centers where the da Vinci Xi system is not available. The patient is placed in dorsal lithotomy position. A 13 mm trocar is placed in the right lower quadrant, a 5 mm trocar is placed in the right upper quadrant, and two 8 mm trocars are placed in the left lower and left upper quadrants. A 6 cm hand port is placed 2 cm above the symphysis pubis as the extraction site. The patient is placed in Trendelenburg with the left side up allowing the small bowel to be delivered outside of the pelvis. The procedure begins laparoscopically. Similar to the complete robotic approach, the inferior mesenteric vascular bundle is identified. Medial-to-lateral dissection commences, identifying the left common iliac and left ureter. A window is made around the inferior mesenteric vessels and is divided with an endovascular stapler. The gonadal vessels are isolated. The peritoneal reflection is then taken down with the hook cautery up to the splenic flexure. At this point the da Vinci robot is docked to the left of the patient and the pelvic dissection begins posteriorly over the tip of the sacral promontory. The lateral stalks are then divided, followed by the anterior peritoneal reflection. Dissection is then continued toward the anus. A rectal exam is done to ensure that dissection is completed 1–2 cm above the dentate line. The rectum is then transected using the robotic stapler. The robot is undocked and the mesentery on the left side is taken down laparoscopically up to the splenic flexure with the LigaSure device. The lesser sac is opened, preserving the omentum, allowing continued dissection of the transverse colon toward the hepatic flexure, making sure to clearly identify the duodenum and keep it out of harms way. The right colon is then mobilized along the white line of Toldt. Finally the hepatic flexure is taken down, again making sure to visualize and protect the duodenum. The rest of the mesentery from the splenic flexure to the ileocolic vessels is taken down with the LigaSure device, preserving the ileocolic vessels. The specimen is delivered into the operative field through the hand port. The ileocolic vessels are then divided with the LigaSure and the GIA stapler is used to transect the terminal ileum. The J pouch and ileoanal anastomosis are then performed as described in the completely robotic approach.

Robotic-Assisted Completion Proctectomy

First, the ileostomy is taken down, stapled off, and returned to the abdominal cavity. The fascia is sutured closed. Trocar and hand port placement are identical to the setup described in the laparoscopic robotic-assisted method for total proctocolectomy with IPAA. If these patients have had a previous laparoscopic or robotic total abdominal colectomy, the same trocar sites are used. Due to previous surgery, there is often a significant amount of adhesions encountered that must be lysed in order to mobilize enough terminal ileum to create the pouch. The patient is then placed in Trendelenburg position with the left side air-planed up. The small bowel is delivered outside of the pelvis. The da Vinci robot is docked to the left of the patient. (If the patient's initial total abdominal colectomy was done as part of a three-stage procedure, with the intent of performing a completion proctectomy in the future, then the inferior mesenteric vascular bundle is purposely left in tact in order to maintain the planes of the pelvis.) The inferior mesenteric vascular bundle is identified and dissected, ensuring to also identify the ureter and iliac vessels. Dissection begins posterior to the rectum in the TME plane. This allows the surgeon to elevate the inferior mesenteric vascular bundle enough to divide it with the robotic vessel sealer. Continued pelvic dissection is now done posteriorly down to the tip of the coccyx. The lateral stalks are then divided, and the dissection finishes by taking down the anterior peritoneal reflection. A digital rectal exam is done to ensure the rectum has been mobilized 1–2 cm proximal to the dentate line. The rectum is divided with the robotic stapler. The specimen is removed and the robot is undocked. Formation of the J pouch and ileoanal anastomosis then proceeds identically as previously described.

Crohn's Disease

Unlike ulcerative colitis, Crohn's disease is a *transmural* inflammatory process that may affect any portion of the gastrointestinal tract. The incidence is highest in Scandinavian countries, followed by Scotland, England, and North America. Similar to ulcerative colitis there is a bimodal age distribution with peak incidence occurring between 20 and 30 years and 60–80 years. It is more common in the Jewish population and in urban areas [6].

The cause of Crohn's disease is still unknown, but is thought to be due to a combination of factors including a genetic susceptibility, triggering infectious agents, defective mucosal barriers, and an inappropriate host response [17]. There has been much research to determine which specific agents are responsible for the development of Crohn's disease. There has also been some data to implicate previous antibiotic use and use of oral contraceptives as risk factors for the development of Crohn's disease [18, 19].

These patients usually present with nonspecific symptoms including abdominal pain, diarrhea, and weight loss. Unlike UC where the rectum is nearly always involved, only half of patient's with Crohn's disease will have rectal involvement. The most common place for Crohn's to occur is the terminal ileum. Anal disease including anal fissures, abscesses, and fistulas plague almost 50 % of patients with Crohn's colitis and 30 % of patients with Crohn's ileitis [6].

Diagnosis is made by a combination of clinical history, endoscopic evaluation, and radiographic imaging. On endoscopy, the mucosa may have a characteristic cobblestone appearance. On gross inspection, the bowel may be surrounded by creeping fat of the mesentery. Because of the transmural nature of this disease, it is not uncommon to see strictures form in the small and large intestine. Histology will reveal edema, lymphoid aggregation, and fibrosis. In 50 % of surgical specimens, noncaseating granulomas will be seen—a pathognomonic feature of Crohn's disease [6].

Medical therapy for Crohn's disease is similar to ulcerative colitis and includes aminosalicylates, corticosteroids, thiopurines, methotrexate, and antitumor necrosis factor agents. A top-down system has in part replaced the traditional step up approach, where treatment begins with the more potent immunomodulatory and biologic medications [20]. Aminosalicylates are the most common medication prescribed for mild to moderate disease. Steroids are generally used for acute flares. TNF-α inhibitors play a pivotal role in the treatment of fistulizing Crohn's disease, where a once exclusively surgical problem is now treated with infliximab in select cases. This shift in management occurred after results from the ACCENT II trial showed that closure of fistulas was possible with the use of this medication [21].

Despite the many advances in medical treatment for Crohn's disease, up to 60 % of patients will eventually need surgery within 10 years of their diagnosis [22], and in those patients with ileocecal disease, up to 83 % of patients will require resection at 10 years after diagnosis [23]. Indications for surgery include disease refractory to medical management, intestinal obstruction, fistulas, intra-abdominal abscesses, massive bleeding, fulminant colitis, cancer, and severe malnutrition. Unlike ulcerative colitis, surgery is not curative for Crohn's disease and many patients will have recurrences after surgical resection, requiring multiple abdominal operations. Therefore, a major tenant in the surgical treatment of Crohn's disease is preservation of as much bowel as possible in order to prevent the development of short bowel syndrome.

The most common surgical procedures performed for Crohn's disease are ileocecal resection, strictureplasty, and segmental colon and small bowel resections. In cases of fulminant colitis, toxic megacolon or disease involving the entire colon and rectum, total proctocolectomy with end ileostomy is indicated. For those wishing to avoid an ostomy in the nonemergent setting, total abdominal colectomy with ileorectal anastomosis may be performed; however, it should be noted that up to 50 % of patients may have a recurrence of disease within ten years requiring completion proctectomy and end ileostomy. In addition, patients who undergo rectal sparing surgery are more likely to require maintenance medical therapy [24].

There is less data for use of the robot in Crohn's disease, because unlike total proctocolectomy with ileal pouch anal anastomosis (the gold standard for surgical treatment in UC), a low pelvic dissection is not routinely necessary in surgery for Crohn's disease, where the goal is symptomatic control rather than cure. In addition, unlike ulcerative colitis where many procedures are done on an elective basis, a large percentage of patients who require surgical intervention for Crohn's disease are already hospitalized. These patients are therefore operated on in a more urgent setting for problems secondary to their Crohn's disease, like bowel obstruction, perforation, and sepsis. In the urgent/emergent setting, use of the robot is less convenient. For those undergoing elective surgery however, the da Vinci single port system is an attractive option especially for this young population where cosmesis is heavily prioritized. A study done by Juo et al. reported on 59 consecutive da Vinci assisted single port colectomies and found that this method was both safe and feasible [25].

An additional advantage the robot has is its excellent articulation, making intracorporeal suturing much easier. This is most useful in obese patients, or patients with a thickened mesentery, where exteriorizing the specimen for extracorporeal anastomosis would be difficult. There have been successful reports of intracorporeal suturing for the Heineke–Mikulicz strictureplasty in Crohn's patients using the robotic platform [26]. Lujan et al. have also shown success with intracorporeal anastomosis during robotic right hemicolectomy [27]. Though no studies have definitively shown a difference in outcomes between intracorporeal and extracorporeal anastomosis, intracorporeal anastomosis does appear to be more feasible with the da Vinci robotic system when it is necessary.

Surgical Technique

Robotic-Assisted Single Incision Colectomy

As stated earlier Juo et al. have successfully reported use of the da Vinci single port system for colectomies. The patient is placed in the dorsal lithotomy position. A single 4 cm vertical incision is made lateral to the umbilicus and the GelPOINT Advanced Access Platform; Applied Medical Inc. Rancho Santa Margarita, CA, USA is inserted. Four trocars are used—a 12 mm trocar for the 30° scope, two 8.5 mm robotic trocars, and a 5 mm laparoscopic trocar. The robot is docked on the side of resection—for right hemicolectomies it is docked to the right of the patient with the base positioned perpendicular to the bed. A "cross armed" technique, which involves crossing of the robotic arms under the fascia, is used to avoid arm collision. The rest of the procedure is performed similar to laparoscopic colectomies [25].

Robotic-Assisted Strictureplasty

The technique reported by Tou et al. involves insertion of the robotic camera in an umbilical port, one robotic arm placed suprapubically and another robotic arm placed in the left upper quadrant. A 10 mm port is placed in the left lower quadrant to allow passage of laparoscopic instruments. A laparoscopic bulldog clamp is use to clamp the proximal small bowel. A longitudinal incision is made over the stricture, and two stay sutures are placed. A two-layer anastomosis is created robotically with a running inner layer and an interrupted outer layer [26].

The da Vinci robotic system has repeatedly been shown to be safe and feasible in colorectal surgery and is especially beneficial in the narrow pelvis. It may allow more cases for inflammatory bowel disease, specifically ulcerative colitis, to be done minimally invasively. This is of significant importance in this patient population where infertility has a profound impact on young childbearing women. Given these benefits, the da Vinci robotic system should be strongly considered for use in the surgical treatment of inflammatory bowel disease.

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Chapter 13
Ergonomics in Robotic Colorectal Surgery

John G. Armstrong and John C. Byrn

Introduction

Improved ergonomic conditions for the operating surgeon are proposed as a cornerstone advantage of the robotic surgical platform. When conceptually applied to colorectal surgery and in particular rectal dissection, the ergonomic advantages of the robotic surgeon console over traditional laparoscopic or open pelvic dissection are almost irrefutable. Sitting at the console with the advantages of magnified three-dimensional vision, surgeon-controlled camera movement, and articulating tremor damping wristed instruments, a vast improvement is apparent over the back-bending-arm-wrenching-torque-creating calisthenic that is required in laparoscopy and open rectal surgery. The trade-off for this improved working environment is both the loss of haptic feedback and the yet to be accurately quantified cost of the platform in comparison to open or laparoscopic surgery.

Recent publications have cited increasing, or previously underreported, levels of occupational injury related to laparoscopic surgery [1–5]. While the benefits for patients became clear early in the development of minimally invasive surgery, the toll of these procedures on surgeons is just recently coming to light. A comprehensive ergonomic survey of members of the Society of American Gastrointestinal and Endoscopic Surgeons notably found that nearly 87 % of responding surgeons reported physical discomfort or symptoms in the neck, hands, upper extremities, or lower extremities that they directly attributed to performing minimally invasive cases [1]. Furthermore, 84 % of respondents reported attempts to change body position and posture to minimize symptoms but 59 % reported slight or no awareness of surgical ergonomic recommendations. Similarly, an ergonomic survey of members

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of the Society of Gynecologic Oncologists found 88 % of respondents reported physical discomfort directly related to minimally invasive surgery with 29 % significant enough to seek treatment. Again, only 16 % reported any ergonomic knowledge or training [2].

The wide level of attention these survey-based reports have generated may mark a tipping point in surgeon awareness of ergonomic factors in their vocation and may prove to be a harbinger for early adaption of robotic approaches to minimally invasive surgery.

In this chapter, we will supply a brief history of ergonomics and surgery and highlight the unique aspects of surgeon strain in open and laparoscopic surgery as compared to robotic colorectal surgery. The organization of ergonomics as it applies to surgery will be approached in the subtopics of visualization, posture, and manipulation with additional discussion of the ergonomics of surgical assistance and the ergonomic effect of lack of haptic feedback.

History of Ergonomics and Surgery

The Greek root words for labor and arrangement, *ergon* and *nomia,* are combined to become the modern word “ergonomics,” denoting the study of a worker’s interaction with their work environment. Ergonomics is also referred to as “human factors” and encompasses the designing of machines, tools, or equipment to optimize the performance of the human user [6, 7]. Efficiency and overall performance, as well as worker well-being, are key components.

The historical origins of ergonomics may be found in the writings of Bernardino Ramazzini, one of the fathers of occupational medicine. In his texts from the 1700s Mobis Artificium Diatriba, or Disease of the Workers, he characterized the hazards of laborers. Additional roots lie in the work of W.B. Jastrzebowski who in 1857 may have been the first to use the word “ergonomy” [7]. Ergonomics advanced at the turn of the twentieth century out of the necessity to assess and optimize skilled military production work. As the field evolved, it expanded widely into industry and other fields including sports and some aspects of medicine [6, 8].

Historically, low cost labor lessened the financial impact of poor ergonomics in industry. This is not the case in the military and sports and is increasingly not applicable to contemporary industrial financial calculations where ergonomic detriment to workers has a definable financial toll [9]. The same may be said of the impact of ergonomics among healthcare workers. Increased interest in ergonomics has occurred recently in healthcare fields including nursing, anesthesia, and dentistry [6–8]. Importantly, poor ergonomics in healthcare workers have been linked not only to direct impact on providers, but to the compromise of patient safety as well [6–8]. For surgeons, despite an awareness of ergonomic shortcomings dating back almost 100 years to the writings of W. Taylor and Frank Gilbreth, the study of ergonomics has been limited [6, 10].

The development and widespread application of minimally invasive surgery has heralded increased concern among surgeons regarding the impact of poor ergonomics in surgery [1–5, 7]. As minimally invasive techniques and laparoscopy have emerged, unique new stressors on the surgeon have revealed themselves. With the development of the robotic platform, the well-documented benefits of minimally invasive techniques for the patient are preserved while the unique stressors of open and laparoscopic surgery on the surgeon are addressed or minimized. Robotic systems allow the design of a more suitable ergonomic platform within the bounds of engineering and patient safety. At a robotic console, a surgeon is free from the ergonomic constraints of direct proximity and contact with the patient, and the necessary awkwardness of handling laparoscopic instruments. The robotic system is not without its own unique ergonomic strains, however, and the costs of these robotic advantages are still being studied. Similarly, the lack of haptic feedback has yet to be addressed from both a safety and surgeon-strain standpoint.

Components of Surgical Ergonomics

In addressing ergonomics in surgery, the literature and most meaningful reviews outline three specific components. These are surgical visualization, surgeon and assistant posture, and surgeon strain during manipulation or dissection. Additional classifications of ergonomics are available (www.iea.cc) but are more readily applied to fields with broader applications and a more robust and quantifiable research foundation.

We will focus on these three applicable ergonomic concepts of visualization, posture, and manipulation and discuss each in the context of a continuum between open, laparoscopic, and robotic surgery.

Visualization

In open surgery visualization relies heavily on exposure. Contemporary issues with patient obesity have led to more than one aching back after open colectomy or proctectomy related to exposure, highlighting what very little is known about the ergonomics of open surgery [11]. A complete summary of surgical training related to ergonomics may begin and end with the dictum, “the table height is the elbow level for the tallest surgeon in the room and everyone else should get a step.” This adage on table height has been tested recently but almost exclusively in the realm of laparoscopic surgery and will be visited in detail when discussing posture. A review of the ergonomics of open surgical visualization by Berguer [6] comes up with no more than two references highlighting proper retractor design [12, 13].

In addition to exposure, operating room lighting is also a key component to surgical visualization. For open surgery this means proper light placement in the theatre itself with ease of rotation and flexibility in positioning to accommodate differing and changing procedure needs [6, 14]. Important lighting concepts are encountered when surgeons cross from open to laparoscopic and robotic surgery. In contrast to open procedures, the light source is no longer diffuse with familiar shadow casting but directional with the light source shining directly on the dissection target. Color and reflection of the tissues may also be unnatural due to a host of camera, light source, and image display inconsistencies. The lighting of laparoscopy more closely resembles an open operation performed with a flashlight shone on the target organs than the familiar well-lit surgical field. In additional, depth cues natural to human vision are missing in laparoscopic surgery due to the monocular vision of the camera and image [15]. Lack of three-dimensional vision and directional lighting, often with unnerving shadow casting, ultimately leads to increases in surgeon visual strain [6, 7]. The toll of the ergonomic strain of unnatural, unidirectional lighting in laparoscopy is not well isolated in studies but has been in part blamed for increased operating times compounding oculo-ergonomic detriment and fatigue [7, 16].

Three-dimensional visualization, as provided by the robotic platform, has been proposed as a significant advantage over laparoscopy for complex and simple tasks with the main outcomes being reduction in task performance time, error rates, and ocular strain. Relatively in-depth study of this aspect has conflicting results based on the experience of the operator and the complexity of the task. When interpreting this literature it is important to try to assess if operating times are the best measure of improvement by three-dimensional vision over two-dimensional vision, and the difficulty in measuring surgical error, ocular strain, and fatigue by either system. Complexity of tasks may or may not mimic complex surgical stress and surgeon experience and comfort with either two-dimensional or three-dimensional vision likely plays an important role. In the authors' experience [15] we found that three-dimensional vision supplied by the robotic system improved operating times and reduced errors for simple tasks for both novice and experienced users. Uniquely in this report we used the robotic platform for both the two-dimensional and three-dimensional arms of the study preserving other robotic benefits, for example, endowristed instrumentation. These results echo many other reports [17–22] but are also balanced by the excellent work of Hannah et al. [23] where three-dimensional vision showed no benefit over two-dimensional vision in simple operative tasks such as laparoscopic colectomy in colorectal surgery.

The most concrete outcome that can be tied to poor visualization is increased operating time. If the surgeon cannot see the tissue of interest and important surrounding structures, greater caution and therefore time must be taken. Commonly, as surgeons with varying levels of expertise transition between open, laparoscopic, and robotic surgical techniques, *uncommon* visualization is often labeled as *poor* visualization. The final word on the ergonomic benefits of the robotic three-dimensional vision has not been spoken and may remain difficult to study.

Another aspect of surgeon visualization in surgery is the role of the assistant who controls or "drives" the camera. In robotic surgery the surgeon-controlled camera platform may provide a benefit in operating time that has not been measured. The benefits of taking camera control out of the hands of assistants are common sense and attempts have been made to mimic this in otherwise laparoscopically performed procedures [24]. In fact, one of the first robotic surgical systems was a voice-controlled robotic camera arm [25].

Lastly, screen location is a well-studied ergonomic aspect of surgery and bridges the concepts of visualization and posture. Extensive literature exists on the effect of video screens on workers in nonsurgical fields summarizing the physical and psychosocial stressors that may vary with a myriad of factors from age and gender to control of work environment [26–30]. The optimal position for viewing the surgical field is at the level of the hands as occurs naturally in open surgery. This view of the hands completing a task is intuitive and familiar. In laparoscopy, a criticism and focus of much attention has been video-monitor placement above the surgeon's line of sight and in off-axis positions necessitated by screens fixed to equipment towers. In laparoscopy, where screen positioning at the hands is not necessarily feasible, a screen position below the surgeon's line of sight is believed to be ideal [29, 30]. In an elegant paper by Hanna et al. [29], the authors timed ten surgeons performing laparoscopic knot tying in a box trainer with variation of the screen location and height. They found statistically significant improvement with practice but also with screen position. The ideal screen location was in front of the surgeon and below eye level. The robotic console clearly is designed with these factors in mind and restores the natural and ergonomic line of sight for the operating surgeon. The benefits of this natural line-of-sight robotic monitor placement in terms of operating times, surgeon fatigue, and surgeon discomfort have unfortunately not been studied in isolation.

Posture

The natural surgical position is standing with dissection view at the level of the hands, as performed most commonly in open abdominopelvic surgery. This posture, however, is not without reported ergonomic detriment [31–34]. These reports have commented on the increased neck-down and back-bent position necessary for open surgery, as well as the strain of axial torsion. In their interesting report on a prototype ergonomic body support for open and laparoscopic surgery, Albayrak et al. [32] discussed at length the strain of open surgery where high levels of concentration in the operating surgeon lead to poor posture, unexpectedly high aerobic work, and ergonomic stress [6, 32]. Although the ergonomic strain on the standing surgeon during open operation is not entirely quantified in the surgical literature, the postural toll of other professions allows extrapolation [35]. In dentists, for example, it is well described that cervicobrachial disorders are directly linked to procedural posture. Importantly, some of the resulting musculoskeletal complaints were indirectly related to years in practice suggesting that with experience and awareness, postural ergonomic detriment may be correctable [36]. Additionally, an observational study of general surgeons, otolaryngologists, anesthesiologists, and scrub and circulating nurses in the operating room revealed extensive postural strain greatest among general surgeons and scrub nurses. In this study as in others, this postural strain was attributed almost entirely to static standing position [37].

In well-designed studies by Szeto and colleagues, the trade-off between increases in static posture seen in laparoscopy and the relief of axial torsion and neck/back bending that laparoscopy provides were quantified using electromyography (EMG) [31, 38]. This relatively advanced and novel application of kinematic instrumentation was used to measure muscle strain of surgeons during the performance of real operations. Conclusions correlated prolonged static posture with low-level muscle tension. In a related publication [38] the authors again used electromyography measurements during real-time surgery with a study aim and conclusions illustrating the increased physical strain of open surgery when compared to laparoscopy.

It is relatively clear that laparoscopy increases static posture but drastically minimizes back and neck bending and axial torsion, assuming correct screen placement. Significant upper extremity ergonomic detriment can persist, however, if table height positioning is not correct. The most ergonomic table height is at the level of the surgeon's elbow. For laparoscopy this may imply a lower than usual table height to account for the artificial increase in table height created by pneumoperitoneum [39–41]. In a representative paper by Berguer et al. [40] the table height was varied while surgeons performed simple tasks in a box trainer. Arm orientation was measured using a magnetometer/accelerometer, muscle strain was measured using EMG, and a survey was completed by the surgeon rating difficulty and discomfort while performing the task. Based on these experiments the authors concluded that laparoscopic instrument handles should be at surgeon-elbow level.

Electromyography

Surface electromyography (EMG) has emerged as a preferred method for quantitative assessment of physical workload in surgical ergonomics [38, 42] *and a brief overview will be provided here. Similar to electrocardiography (ECG), surface electromyography uses metallic electrodes placed on the skin to record the electrical activity of muscle. Applications are varied and include rehabilitation, sports training, diagnosis and monitoring of muscular disorders, and ergonomic evaluation of workplace design. In the evaluation of surgical ergonomics and similar tasks, the electrical activity of specific muscle groups and thus actions are evaluated by placement of electrodes at specific normalized positions overlying each muscle group of interest. Differences in the EMG patterns and activity of major neck and shoulder muscle groups are correlated with occupational discomfort* [43, 44].

Measurement starts with a recording from each individual muscle group of isometric voluntary maximum exertion or contraction. This reference allows the recorded EMG data to be reported as percentage of maximum voluntary exertion or contraction. Adding time allows the calculation of cumulative muscular workload over a task performance period [38, 42]. *In addition to cumulative workload* *and percentage of maximum, muscle activity is also quantified by number and frequency of exertions, peaks of exertion, and number and frequency of rest periods. Data collection is often accompanied by video recording to correlate EMG data to specific movements or techniques in a real operative setting or the manipulation of specific variables in a laboratory setting.*

It has been recommended that a sitting position may be ideal for parts if not all of some operations [6, 7]. These recommendations are based largely on extrapolation from other forms of fine labor and are not without realization that this lends indirect endorsement to the robotic platform. Clearly ergonomic strain related to static standing, upper extremity exertion, and screen visualization is to some extent relieved by the seated position and line-of-sight visualization of the robotic console. An understudied but important concept of the seated console as it pertains to postural strain is the ability to clutch the hand grips freely to a neutral elbow level position. This important ergonomic adaption is also one that may be of benefit as surgeon experience increases and clutching to the neutral becomes almost subconscious. The robotic console, however, is not a panacea of surgeon ergonomic strain as other medical professions with seated procedures are exposed to physical detriment and continued study of the ergonomic robotic console is warranted.

Manipulation

Open surgical tissue manipulation and dissection will always be the gold standard to which minimally invasive dissection is compared. The exposure of open surgery allows room for maneuverability, tactile familiarity and feedback, and the use of instruments refined over hundreds of years. The comfort and familiarity of handling the open colon, arterial pedicles, or even controlling deep pelvis surgical bleeding with two gloved hands, open retractors, and an army of body wall—wielding surgical assistants will likely never be replicated in laparoscopic or robotic surgery. While the postural toll of open surgery has been investigated and has known detriments, open surgical tissue manipulation is more akin to open visualization in that ergonomic study is supplanted by the understanding of open manipulation as surgical bedrock.

In minimally invasive surgery, a surgeon loses the ability to use touch and direct tissue interaction as a guide in tissue manipulation. Laparoscopic instruments themselves, many of which are not task specific but retrofitted from other applications and fields, pose many obstacles [1, 45]. The length of laparoscopic instruments is a primary issue where the rigidity and length magnify tremor. Additionally, the length increases the surface area that during movement creates friction with the trocar, tissue, or drapes and limits an already impaired tactile feedback. Aside from the friction of the trocar affecting tactile feedback, the trocar and its static location and small aperture severely limit maneuverability. The fulcrum effect or fulcrum point created by the trocar at the abdominal wall results in counterintuitive movements of the hand and tool [6, 46]. Rightward external hand movements result in leftward tool deflection or camera panning, thus creating a disconnect between visualization and proprioception.

A laparoscopic instrument is also limited to movement in a cone shape with the height of this cone determined by constantly changing insertion length. This requires wide arc-like movements of the surgeon's upper extremity to accomplish small movements of the instrument tip [46]. The constantly changing arc-like dimensions and angles combined with decreased tactile feedback make the determination of the force required or appropriate when handling tissues laparoscopically challenging. It has been shown that the relationship between the input force at the handle of a laparoscopic instrument and the output force exerted on the tissues is nonlinear where greater force must be exerted at the handle for a desired effect at the tissue [47, 48]. The determination and application of appropriate force is a unique challenge in laparoscopic surgery foreign to the open surgeon.

Trocar placement and needed access to multiple quadrants in colorectal surgery can create ergonomic challenges that result from inopportune angles when trocars are employed for surgical approaches outside of their most useful perspective. The most classic example is the need for the primary surgeon to reach across the patient's body and use a trocar placed for an assistant as a primary dissection or retraction port. The need for this type of stretch is often short lived but the ergonomic toll may not be. An additional consideration in laparoscopy is the standard pistol grip of most laparoscopic instruments [49]. The literature has documented thenar neuropathies, "laparoscopic surgeons' thumb," which have been attributed almost directly to the extreme force and position created by the pistol configuration. Axial design of laparoscopic instrumentation has been adopted for laparoscopic needle drivers but not been widely adapted for most other dissection instrumentation.

Important in the discussion of surgical manipulation is degrees of freedom or the potential for independent movement in a particular direction or rotation about an axis [50]. The tip of a surgeon's finger during an open procedure is said to have 36 degrees of freedom when considering the body, limb, and finger. A laparoscopic instrument is limited to only four degrees of freedom. These are rotation or roll along the long axis, in and out of the trocar, side-to-side waggle also known as yaw, and up and down also known as pitch. A free moving object is said to possess at least six degrees of freedom. For comparison, the human upper extremity has seven degrees of freedom. The shoulder and wrist each have pitch, yaw, and roll while the elbow only has pitch [50]. The robotic system and the EndoWrist® instruments mirror this in their design with restoration of six degrees of freedom plus tool articulation or grip which some consider a seventh degree of freedom [7, 51]. The importance of just a few extra degrees of freedom is significant as it has been shown that the increase from four to six degrees of freedom is associated with an increase in quantified robotic dexterity by a factor of 1.5 [7, 52].

In addition to increased degrees of freedom and movement, the robotic platform provides other benefits in tissue manipulation. The articulated instruments and computer control allow for elimination of the fulcrum effect of standard laparoscopy. Hand movement and visualization are again synced and articulation allows for movements beyond that of a simple cone. The robotic system also possesses the ability to filter high frequency oscillation of hand tremor to provide smooth and stable movements. In addition, computer control is able to scale movements and angle so that macro hand movements are translated into micro movement at the instrument tip for improved precision and dexterity beyond that of natural human ability [7]. Despite these advantages, the robotic platform provides no tactile feedback so key to open surgery and present in standard laparoscopy. Instead, in robotic cases a surgeon must rely solely on visual cues from the superior robotic visual system and experience with the involved tissues. The lack of haptic feedback and reliance on visual cues for "touch" is the least intuitive aspect of the robotic platform and ultimately results in "conscious inhibition" and the concept of "carefulness" [7]. This concept may in part explain the longer operating times [53] seen in robotic colorectal surgery along with learning curve-related aspects of this newer technique.

Ergonomics of Assisting in Minimally Invasive Surgery

The active support roles in laparoscopic surgery are varied and may include an assistant grasping, retracting, or driving the laparoscope while maintaining prolonged static postures. Aside from a limited number of studies focusing on camera control, the laparoscopic assistant is an understudied yet integral and active surgical team member, and one that can sustain ergonomic injury [54]. An assistant is subject to the same ergonomic challenges of visualization, posture, and to an extent manipulation as the operating surgeon, though nearly all studies examining these are designed around the operating surgeon. This follows a general understanding that in the operating room, the priority is the comfort and support of the operating surgeon foremost.

As countless medical students and residents with shaking arms and aching backs can attest, positioning of the assistant to accommodate the operating surgeon presents its own unique ergonomic challenges, even if anecdotal. It has been shown in simulated cases that laparoscopic assisting is associated with disproportionate postural balancing with up to 80 % of body weight distributed to only one leg over the time period of an operation [55]. Due to the fulcrum effect discussed previously, this disproportionate balance is made worse when assistants must view or manipulate near objects as this requires more extreme body positioning.

The robotic platform with surgeon console-controlled camera movement and the control of additional robotic arms limits the need for assistants to perform these tasks at the bedside. While some cases require a bedside assistant to perform occasional tasks such as suction, additional retraction, or delivering suture, these result in a more limited exposure to the prolonged static postural balancing and contortions of standard laparoscopy.

Challenges of Robotics and Ergonomics

The status of open surgery as the ergonomic benchmark in surgery is quietly fading. The benefits of laparoscopic surgery to patients have exerted pressure on contemporary surgeons to master these minimally invasive techniques. As this occurs and the national and per surgeon volume has risen, the ergonomic toll of laparoscopy is coming to light. In the preceding sections we have detailed the major aspects of ergonomic strain on the open, laparoscopic, and robotic surgeon. The design of the robotic surgeon console was clearly not accidental, as the robotic platform at least partially addresses each of the major ergonomic challenges of laparoscopy: improved three-dimensional visualization with screen at the level of the surgeon's hands, sitting position with nonpistol grip hand pieces that are clutched to the rested elbow level, and tremor reducing, endo-wristed instruments that restore in part the degrees of freedom of the surgeon's hand while eliminating the excessive force and exaggerated movements necessary for dissection in laparoscopy. Additionally, the robotic platform gives the surgeon control of the camera and minimizes the need of an assistant and the ergonomic strain on the cosurgeon.

Three aspects of the robotic platform, however, are worthy of mention as areas of potential ergonomic detriment. First, detractors of robotic surgery have long considered the lack of haptic feedback of the robotic platform an Achilles' heel [56, 57]. Undoubtedly, the inability to "feel" the tissues under dissection is a limitation but most experienced robotic surgeons find this surmountable. An interesting and potentially dangerous phenomenon does exist, however, where the experienced laparoscopic surgeon accustomed to exerting excess force in dissection comes to a robotic platform where feel is absent and minimal force is needed for dissection. This naturally leads to a cautious and careful dissection, which ultimately may lengthen operative time. This increase in operative time is the second ergonomic concern, potentially leading to both visual and mental ergonomic strain. Three-dimensional vision is a new and unfamiliar view, the magnification and view is extreme in its quality, and the dissection may be painstaking for the novice robotic surgeon. These factors undoubtedly lead to a palpable fatigue which is difficult to study in the novice or experienced surgeon and is not captured in the ergonomic or learning curve-related literature [58]. Additionally, operative time itself can be a risk factor for complications and timely completion of a case is paramount in the minds of many surgeons. Lastly, the concept of operative room crowding and distraction is taken to new levels by the robotic platform [59]. In this report the anecdotal toll of the additional wires, cords, and tubes needed for a laparoscopic case is quantified. For a robotic case this is only amplified and in many instances surgeons use a hybrid approach where the laparoscopic and robotic approaches and instrumentation are both used.

Summary and Future Directions of Study

The issues raised in Cuschieri's excellent commentary [60] regarding the challenges facing surgeons early in the laparoscopic era are still applicable today in laparoscopy and robotics. The important concept of surgical fatigue syndrome was introduced in this report. Coupled with the concept of "conscious inhibition" or "gentleness" [7] this may be a summation of the ergonomic detriments of robotic surgery as an initially *unfamiliar*, albeit ergonomically advantageous, platform. In short and stated more simply, the ergonomic benefits of the robotic platform, "take some getting used to."

The ergonomic strain of laparoscopic colorectal surgery and the ergonomic benefits of the robotic platform continue to suffer from lack of study. This is at least in part due to the difficulty of ergonomic study in all fields and especially surgery. In colorectal surgery, the complex procedures and myriad of variable patient factors impacting ergonomic toll make controlled ergonomic studies difficult. Future study will need to evaluate the perceived robotic ergonomic advantages in visualization, posture, and manipulation and weigh them not only against identified ergonomic detriments but as factors in surgeon well-being, healthcare finances, and patient safety.

Robotic ergonomic advantages	
Visualization	Exposure
	Three-dimensional vision
	Surgeon camera control
	Line of sight screen location
Posture	Seated position
	Line of sight screen location
	Free of limits of sterility
Manipulation	Seven degrees of freedom
	Articulated instruments
	Elimination of fulcrum effect
	Cancellation of tremor
	Scaling of movement

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Chapter 14
Nerve Preservation in Robotic Rectal Surgery

Fabrizio Luca and Manuela Valvo

Introduction

In recent decades colorectal carcinoma has become the second most common cancer in Europe and the United States both in males (after lung cancer) and in females (after breast cancer) [1]. The principal goal of rectal cancer treatment is cure, and in recent years we have seen an increase in survival from rectal cancer, due largely to advances in surgical techniques such as total mesorectal excision (TME), earlier diagnosis, and the improvement of efficacy of adjuvant radio- and chemotherapy [2, 3].

Conventional outcomes such as survival, tumor recurrence, and complication rates after surgery for rectal cancer have been rigorously assessed, but the importance of preserving quality of life after intervention has received less attention.

Before the introduction of total mesorectal excision (TME), the incidence of sexual and urinary dysfunction was high with rates reported from 10 to 30 % and 40 to 60 %, respectively [4–6]. When preservation of the autonomic nervous system during surgical rectal resection was integrated into the therapeutic scheme for treatment of rectal cancer, the incidence of postoperative sexual and urinary complications decreased to the range of 10–35 %, and <5 %, respectively, and the rate of local recurrence also decreased [7–9].

In fact TME is currently considered the optimal technique for resection of rectal cancer, providing superior oncological and functional outcomes, yet despite the incorporation of autonomic nerve-preserving techniques, sexual and urinary dysfunctions remain severe complications of rectal surgery, representing the factors that most influence patient's quality of life [10].

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Quality of life (QoL) is an important outcome measure that has to be considered when deciding treatment strategy for rectal cancer [11–13], yet only a few studies have been published to date concerning QoL, urinary function, and sexuality after colorectal resection [14].

Sexual and urinary dysfunctions after colorectal cancer treatment are mainly caused by surgery, because of the close anatomical correlation between the pelvic nerves and the mesorectum, and the difficulty of identifying small anatomical structures such as the nerves of the inferior hypogastric plexus, particularly in a narrow space such as the pelvis [15]. Other possible risk factors include patient demographics, tumor location, blood loss, anastomotic leakage, and treatment-related variables [16, 17]. It has also been reported that preoperative radio-chemotherapy has an adverse effect on the ability to achieve and maintain an erection, in comparison with patients undergoing surgery alone [18]. The most common symptoms of urinary dysfunction are stress incontinence, urgency, elevated frequency of voiding, difficulty in emptying the bladder, loss of bladder fullness sensation, and overflow incontinence. In male patients sexual dysfunction includes impotence and retrograde ejaculation [19]. Results of study of male sexual function after conventional rectal cancer surgery show erectile dysfunction rates ranging from 20 % to nearly 80 %, while ejaculatory problems were reported to range from 20 to 70 % [16, 20–23].

Specific sexual problems in women after surgery treatment of rectal cancer are loss of libido (41 %), loss of arousal (29 %), loss of lubrication (56 %), lack of orgasm (35 %), and dyspareunia (46 %) [22]. Knowledge regarding sexual function and physiopathology of sexual response in the female has been investigated less deeply and is more limited [23].

Inflammatory change in paravesical tissues and posterior tilting of the bladder after an anterior or an abdomino-perineal resection have been claimed to cause difficulties in bladder emptying. However, urinary and sexual dysfunction caused by bilateral resection of the inferior hypogastric plexus are severe and often permanent [24].

Anatomy and Physiology of Urinary and Sexual Function

The superior hypogastric plexus (Fig. 14.1) is formed by the union of numerous sympathetic filaments, which descend on either side, in front of the aorta, close to the inferior mesenteric artery as a continuation of the preaortic sympathetic trunks. It continues between the two common iliac arteries and the promontory of the sacrum and then, at this level, the superior hypogastric plexus divides into two distinct branches: the right and left hypogastric nerves that run along the posterior and lateral aspect of the mesorectum, outside of the mesorectal fascia. The parasympathetic nerves arising from the sacral roots S2, S3, and S4 run along the sacrum and, on each side, join the hypogastric nerves to form the inferior hypogastric plexus (Fig. 14.2).

These structures are situated at the sides of the rectum in the male, and at the sides of the rectum and vagina in the female. They constitute the peripheral afferent and efferent innervation of all the pelvic organs.

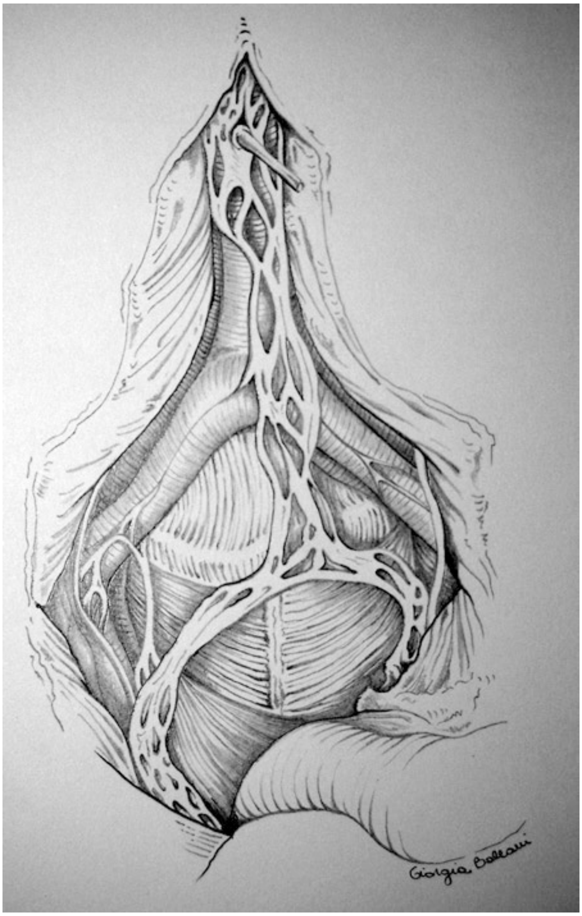

Fig 14.1 Front view of the lower abdomen and the pelvis illustrating the course of the superior hypogastric plexus and of the hypogastric nerves

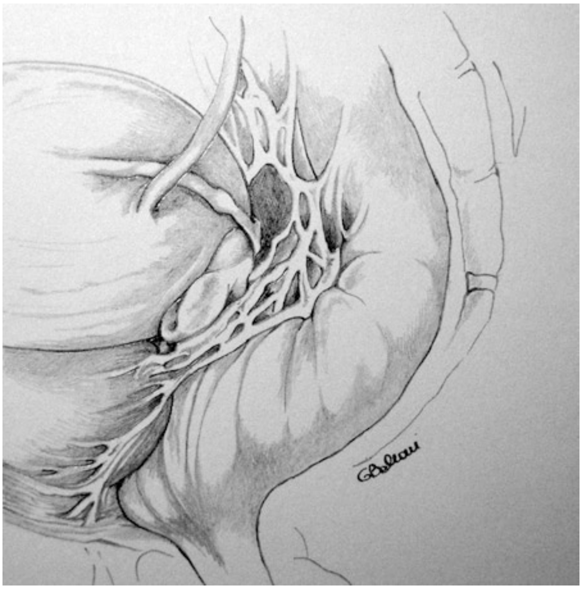

Fig 14.2 Lateral view of the male pelvis illustrating the hypogastric plexus and its anatomical relationship with the seminal vesicles

The superior hypogastric plexus is responsible for the sympathetic innervation of the bladder, rectum, uterus, uterine tubes, and genitals. It also carries the major part of visceral sensitive fibers originating from pelvic organs.

In men, sympathetic nerve stimulation causes seminal emission as a result of the contraction of nonstriated muscle of the genital tract and the contraction of the sphincter of the bladder neck, to prevent reflux of ejaculate into the bladder. A lesion of the superior hypogastric plexus is thus commonly associated with ejaculatory dysfunction [6].

In women, the interaction between the sympathetic and parasympathetic systems is complex and remains largely unknown; however, it has generally been presumed that a lesion to the superior hypogastric plexus can lead to impaired vaginal lubrication and dyspareunia or discomfort.

In both sexes the sympathetic system takes part in the continence mechanism. The superior hypogastric plexus inhibits the detrusor muscle of the bladder, stimulates the contraction of the smooth muscle in the bladder neck, and inhibits the parasympathetic system facilitating the storage of urine.

Erection is mainly under the control of the parasympathetic innervation that reaches the penis via the nervi erigentes. Its activity leads to the relaxation of the smooth muscles in the corpora cavernosa of the penis causing the engorgement of this erectile tissue. In the male an injury to the proerectile fibers of the parasympathetic system results in erectile dysfunction and impotence.

As with males, in females the parasympathetic activity is responsible for the vasocongestion response in this case resulting in vaginal, labial, and clitoris swelling [25]. The blood engorgement stimulates the vaginal walls to exude and p*arasympathetic* nerves directly stimulate *Bartholin's glands* to secrete mucus, providing vaginal lubrication.

An injury to the parasympathetic nerves can cause a diminished labial swelling and lubrication response in the female.

During voiding parasympathetic stimulation causes the detrusor to contract and the internal urethral sphincter to relax. When the nerve is damaged the bladder becomes noncontractile due to the detrusor hypoactivity resulting in overflow incontinence [14, 26].

Despite the advantages of a minimally invasive technique, laparoscopic rectal surgery is associated with a rate of sexual dysfunction which is similar or higher [27–31] when compared with the open approach. The reason has been attributed to the technical complexities of this type of surgery such as the unstable two-dimensional view of the operative field and the poor ergonomics of the surgical tools, which render complex operation even more difficult, with a higher degree of surgeon fatigue and a steep learning curve [32–34].

In the context of minimally invasive surgery, the most recent innovation is robotic surgery. The first robotic colorectal surgery was performed in 2002, and in the following years many authors have demonstrated that robotic TME is an oncologically safe and feasible procedure that facilitates mesorectal excision [35, 36]. The magnified vision, the superior dexterity, and precision of movements of the robotic arms allow the surgeon a better view and greater ergonomic comfort for the dissection of the small anatomical structures [36–38].

The improved view of the small anatomical pelvic structures together with the more precise and accurate dissection offered by the robotic system during mesorectal resection can help the surgeon to recognize the inferior hypogastric plexus and to reduce the risk of collateral damage to the pelvic autonomic nerves. As a result of these advantages, robotic nerve-sparing TME allows for better preservation of urinary and sexual function when compared with the literature data on both open and laparoscopic surgery [39].

Key Points for Nerve-Sparing Surgery and Surgical-Related Lesions

Four main zones have been identified as being at high risk for nerve injury during total mesorectal excision [40–42]:

1. Ligation of the inferior mesenteric artery
2. Posterior dissection of the mesorectum
3. Lateral dissection of the mesorectum
4. Anterior isolation of the rectum

Moreover, damage to the pelvic nerves may occur during intersphincteric resection or abdominoperineal resection.

Ligation of the inferior mesenteric artery: ligation or stapling at the origin of the inferior mesenteric artery has the objective of complete removal of the regional lymph nodes. To avoid injury to the superior hypogastric plexus, it is important to identify the nervous fibers that run along the aorta and gently displace them before dividing the IMA (Fig. 14.3).

Sharp dissection is then continued down in order to identify the virtual space between the fascia propria of the mesorectum and the presacral parietal fascia. If the

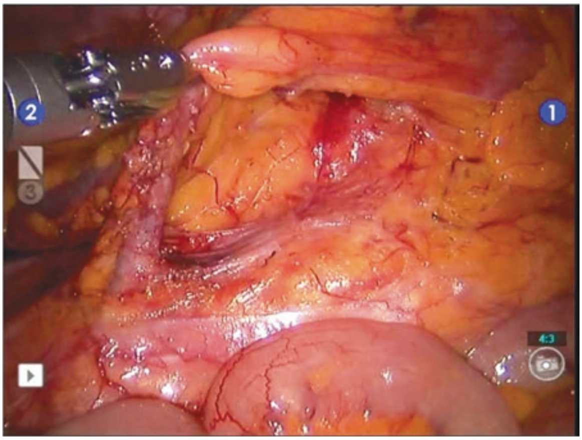

Fig 14.3 Isolation of the IMA. The small neurons lying in front of the aorta are identified and respected

posterior plane of dissection of the mesorectum is correct, then it should be easy to identify the hypogastric nerves. If the dissection is carried below the parietal fascia an injury to the hypogastric nerves can occur. Conversely, if the dissection plane is too superficial the mesorectal fascia will be infracted. This can affect the quality of the specimen and is directly associated with the risk of local recurrence, as demonstrated by Quirke and Dixon [43].

Particular attention should be paid to the **lateral dissection** of the mesorectum. At this level the hypogastric nerves run adherent to the fascia propria and can be easily injured. A typical mistake occurs when the dissection is not performed in a "posterior to anterior" fashion but the mesorectum is freed posteriorly, anteriorly, and then tractioned to one side to complete the isolation. In this case the nerve is usually pulled medially and transected together with the tissue that some authors consider to represent the lateral ligament of the rectum. When the dissection is carried out from the posterior to the lateral aspect of the mesorectum, it is almost always possible to identify the hypogastric nerves and isolate them sharply without the need for clamping or excessive electrocoagulation close to the neural structures. This technique is also useful to reduce prolonged and extensive traction of the nerves.

The dissection then proceeds toward the **anterior isolation of the rectum** where this organ is in close contact with the nerves that originate from the inferior hypogastric plexus and carry both sympathetic and parasympathetic fibers to the bladder and sexual organs via the neurovascular bundles. They are located lateral to Denonvillier's fascia in close proximity to the seminal vesicles. Every effort should be made to preserve both bundles when not involved by the tumor. If both nerves are sectioned, the rate of impotence will be 100 % [44]. However, potency rates will decrease substantially even when only one of the neurovascular bundles is left intact [45, 46].

In the case of involvement of the anterior wall of the rectum by the tumor, Denonvillier's fascia should then be removed, as described by Heald, in order to reduce the risk of a positive circumferential margin. However, particular attention should be paid when dissecting the lateral margins of the rectoprostatic fascia and the rectovaginal septum that are in close relationship with the fibers of the inferior hypogastric plexus for the genitalia.

In most cases, when there is no anterior extrafascial extension of cancer and therefore no risk of neurovascular bundle involvement, it is possible to maintain the dissection plane closer to the mesorectal fascia and away from the seminal vesicles. When the tumor is located in the posterior rectal wall Denonviller's fascia can be preserved [15, 47].

Different mechanisms of nerve lesions are considered to lie at the basis of genitourinary dysfunction in **intersphincteric and abdominoperineal resection**. A more extensive pelvic dissection, with an increased risk of pelvic nerve injury is common for both types of operation: different studies have shown a direct correlation between the distance of the tumor from the anal verge and the postoperative dysfunction rates [24, 48, 49]. There is nonetheless a general consensus that abdominoperineal resection has the worse functional outcomes [7, 18, 50–52]. The distortion of pelvic floor anatomy may not only lead to a loss of support for the urethra and the bladder but may also alter the mechanism of contraction of the bulbocavernous muscle which is involved in erection function and ejaculation [53, 54].

Instrument Use and Surgical Techniques

Various techniques and approaches have been developed for robotic total mesorectal excision [55–61]. However, most of the principles and points to be considered for the preservation of the autonomic nerves during surgical dissection are similar regardless of the technique applied.

Thermal, mechanical, and vascular damage are the principal causes of nerve injury and consequent urinary and sexual dysfunction. The extensive use of electrocoagulation should be avoided in particular on the lateral plane of dissection due to the anatomical proximity between the mesorectal fascia and the hypogastric plexus, and on the anterolateral plane, near the vesicles, where the neurovascular bundle is in close contact with the rectum. When needed, surgical clips should be applied for hemostasis. Excessive traction has been identified as a cause of neuropraxia that can lead to a temporary or unrecoverable blockage of nerve conduction depending on the grade and the duration of the traction [62, 63]. Delicate handling of the neurovascular tissue is also important to preserve the vasa nervorum and to prevent ischemic damage to the nerves. Traction-free techniques and gentle handling can be difficult during the learning curve phase in robotic surgery due to the absence of haptic feedback, when the surgeon has not yet learned to compensate this lack of sensation with visual integration. This issue is also important for the assistant surgeon whose main function is, for the most part, to provide countertraction during the intervention. Trainees should be instructed to avoid excessive tension during tissue manipulation [64].

The identification of all the components of the hypogastric plexus is of paramount importance to reduce the incidence of genitourinary dysfunction and injury can occur if the autonomic nerves cannot be kept under visual control during the dissection [65–68]. For this reason bleeding control is important because excessive blood in the operating field can make it very difficult to identify the nerves [13, 69]. The three-dimensional magnified High Definition view coupled with a stable camera platform offered by the da Vinci System helps in recognizing the smaller anatomical structures of the inferior hypogastric plexus and the anatomical planes, in particular during the anterior isolation of the mesorectum, which represents the most dangerous phase, where there is a high risk of lesion to the neurovascular bundle. The significant reduction of intraoperative blood loss reported may also contribute to the identification of the autonomic nerves [18, 70]. Moreover, the stability and superior movements with the increased flexibility and precision of robotic arms permit a more accurate dissection, especially in narrow spaces such as the conically shaped male pelvis and reduce the risk of collateral damage to surrounding tissues [56]. Quality of dissection and preservation of sexual and urinary function are, in fact, directly related [71] (Fig. 14.4). As a mnemonic for the trainee

Fig 14.4 Robotic TME specimen showing shiny intact mesorectal surface

Table 14.1 The CLEAN acronym: a mnemonic aid for performing a correct nerve-sparing technique

C	**C**ircumferential: the isolation of the mesorectum should be circumferential, from posterior to anterior following the principles described by Heald
L	**L**ight: as the tension that should be applied on the anatomical structures
E	**E**lectrocoagulation free
A	**A**traumatic: to preserve the nerves and the vasa nervorum
N	**N**erve guided: during TME the autonomic nerves should be identified and followed

surgeons starting their surgical activity at the console we explain that robotic nerve sparing total mesorectal excision should be **CLEAN**: **C**ircumferential from posterior to anterior as described by Heald; with **L**ight tension on the structures; **E**lectrocoagulation-free; **A**traumatic to preserve the vasa nervorum and **N**erve-guided: following the autonomic nerves (Table 14.1).

Conclusions

The primary objective of rectal cancer surgery is to obtain oncologic radicality to thereby minimize local recurrence. However, quality of life (QoL) is an important variable of oncological excellence and the ideal approach for the prevention of genitourinary complications of rectal cancer treatment is multidisciplinary with a close collaboration between the different specialists.

Since the inception of techniques aiming at the preservation of the autonomic nervous system during TME, the incidence of sexual and urinary dysfunctions has decreased.

The da Vinci surgical system is a powerful tool that offers more precision, more dexterity, and a better view of the operating field during total mesorectal excision. Nevertheless, we should bear in mind that the robot only enhances the skills and the capabilities of the surgeon. To achieve good results it is essential to have a sound knowledge of pelvic neuroanatomy and of the principles of nerve-sparing total mesorectal excision.

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Chapter 15
Completed and Ongoing Trials in Robotic Colorectal Surgery

Robert K. Cleary

Introduction

The minimally invasive revolution for colorectal disease that started in 1990 was scrutinized and studied, culminating in randomized trials comparing the laparoscopic approach to open surgery. These studies demonstrated that oncologic outcomes were equivalent for colon cancer and that other relevant outcomes including hospital length of stay (LOS), recovery time, and cosmesis were improved with the minimally invasive approach [1–5]. These laparoscopic advantages have not been universally replicated for rectal cancer with respect to oncologic margins and hospital LOS [2, 6].

Laparoscopic surgery is a technically challenging platform. Only 40–45 % of elective colon surgery, and only 10 % of elective surgery for rectal neoplasia are performed by the laparoscopic approach, a testament to the degree of difficulty [7–9]. The penetration of laparoscopy into practice has not been widely adopted even among young, fellowship-trained colorectal surgeons. In a survey of the American Society of Colon and Rectal Surgeons Young Surgeons group, Steele et al. learned that young fellowship-trained colon and rectal surgeons utilize laparoscopic techniques only 23 % of the time for sigmoid colectomies, 26 % for right colectomies, and 20 % for low anterior and abdominoperineal resections [10]. If minimally invasive surgery is to reach a larger segment of the colorectal surgery patient population, there is clearly a need for a less demanding minimally invasive platform.

The first daVinci® surgical system was FDA approved in 2000 and the first da Vinci surgical procedure was performed in 2001 [11]. The emergence of technologic advances in robotic surgery offers markedly enhanced imaging, articulating

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instruments that allow better angles for dissection and hemostasis, surgeon control of a stable camera platform, and surgeon control of a 3rd arm for fixed retraction. Continued upgrades in robotic systems suggest that the potential for continued growth in this platform may result in paradigm shifts in the conduct of minimally invasive colorectal surgery [12].

Studies to date are mostly case series and comparative studies. There are a few meta-analyses. The results of three small, randomized trials have been reported and one large randomized trial (ROLARR) has been completed, the results of which were presented at the American Society of Colon and Rectal Surgeons Annual Meeting in 2015 [13–16]. Representative studies are summarized in Tables 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, and 15.9.

Table 15.1 Conversions: rectum

	N robot	N lap	Conversions robot	Conversions lap	*P* value
Pigazzi [53]	6	6	0.0	0	NS
Baik [13]	18	18	0.0	11.1	NS
Patriti [54]	29	37	0.0	18.9	**<0.05**
Baik [55]	56	57	0.0	10.5	0.013
Park [56]	41	82	0.0	0	NS
Pigazzi [46]	143		4.9		
Bianchi [57]	25	25	0.0	5	NS
Baek [42]	64		9.4		
Baek [63]	41	41	7.3	22	NS
Trastulli [83]	344	510	2	7.5	**0.0007**
Kwak [66]	59	59	0.0	3.4	0.496
Park [68]	52	123	0.0	0	NS
Kang [60]	104	97	0.6	1.8	NS
D'Annibale [58]	50	50	0.0	14	**0.011**
Ielpo [69]	56	87	3.5	11.5	0.09
Shiomi [52]	113		0.0		
Tam [89]	409	2326	7.8	21.2	**<0.001**
Bhama [90]	331	3057	10	13.7	**0.01**

Table 15.2 Conversions: colon

	N robot	N lap	Conversions robot	Conversions lap	*P* value
deSousa [31]	40	135	2.5	0.7	NS
Tyler [33]	160	2423	6.3	10.5	**<0.001**
Trastulli [38]	102	94 EC	3.9	8.5	
		40 IC	3.9	15	**0.07**
Casillas [37]	146	200	4 (right)	11	**0.04**
			4 (left)	8	0.36
Tam [88]	409	2326	9	16.9	**0.06**
Bhama [90]	299	7790	9	10.7	0.36

EC extracorporeal anastomosis, *IC* intracorporeal anastomosis

Table 15.3 Operating time: rectum

	N robot	N lap	OR time robot	OR time lap	*P* value
Pigazzi [53]	6	6	264	258	NS
Patriti [54]	29	37	202	208	NS
Baik [55]	56	57	190	191	NS
Park [56]	41	82	232	168	**<0.001**
Bianchi [57]	25	25	240	237	NS
Kim [64]	62	147	390	285	**<0.001**
deSousa [61]	36	51	338	274	**0.03**
Baek [63]	41	41	296	315	NS
Kwak [66]	59	59	270	228	**<0.0001**
Patel [67]	70	60	237	182	**<0.01**
Park [68]	52	123	232	158	**<0.001**
Baek [65]	154	150	285	220	NS
Kang [60]	104	97	310	278	**<0.001**
Park [59]	40	40	236	185	**<0.001**
D'Annibale [58]	50	50	270	275	NS
Ielpo [69]	56	87	309	252	**0.023**
Bhama [90]	331	3057	255	212	**<0.001**

Table 15.4 Hospital LOS: rectum

	N robot	N lap	LOS robot	LOS lap	*P* value
Patriti [54]	29	37	9.6	11.9	NS
Baik [55]	56	57	5.7	7.6	
Park [56]	41	82	9.9	9.4	NS
Bianchi [57]	25	25	6.6	6	NS
Kim [64]	62	147	12	14	**0.05**
deSousa [61]	36	51	7	7.3	NS
Baek [63]	41	41	6.5	6.6	NS
Patel [67]	70	60	2.9	3.9	**<0.01**
Park [68]	52	123	10.4	9.8	NS
Baek [65]	154	150	11.1	10.8	0.82
Kang [60]	104	97	10.8	13.5	**<0.001**
Park [59]	40	40	10.6	11.3	0.11
D'Annibale [58]	50	50	10	8	**0.034**
Ielpo [69]	56	87	13	10	0.26
Bhama [90]	331	3057	4.5	5.3	**<0.001**

Table 15.5 Operating time/LOS: colon [1]

	N robot	N lap	OR time robot	OR time lap	*P* value	LOS robot	LOS lap	*P* value
Delaney [26]	6	6	165	108		3	2.5	NS
D'Annibale [27]	53	53	240	222	NS	10	10	NS
Rawlings [29]	30	27	219 right	169 right	**0.002**	5.2	5.5	0.86
			225 sigmoid	199 sigmoid	0.128	6.0	6.6	0.85
Spinoglio [30]	50	161	384	266	**<0.001**	7.7	8.3	0.928
deSousa [31]	40	135	159	118	**<0.001**	5	5	0.86
Bertani [71]	34	30	194	210	NS	5	5	NS
Luca [72]	33	102	192	136	**<0.001**	5	8	**<0.001**
Deutsch [32]	79	92	219 right	214 right	0.75	4.3 right	6.3 right	0.13
			290 left	255 left	**0.0006**	4.1 left	4.2 left	0.71

Table 15.6 Operating time/LOS: colon [2]

	N robot	N lap	OR time robot	OR time lap	*P* value	LOS robot	LOS lap	*P* value
Morpurgo [35]	48	48	266	223	**<0.05**	7.5	9	**<0.05**
Lim [36]	34	146	253	218	**0.016**	5.5	6.2	**0.005**
Casillas [37]	146	200	143 right	79 right	**<0.01**	6.2 right	5.5 right	0.47
			188 left	109 left	**<0.01**	3.6 left	6.5 left	**0.01**
Trastulli [38]	102	94	287	208	**<0.0001**	4	7	**<0.0001**
		40	287	204	**<0.0001**	4	5.5	NS
Trinh [39]	15	25	258	191	0.183	9.6	6.5	0.091
Tam [89]	409	1511CL	168	136	**<0.0001**	4	4.44	**0.04**
		815HAL	168	135	**<0.0001**	4	4.41	**0.008**
Bhama [90]	299	7790	211	167	**<0.001**	4.3	5.3	**<0.001**

CL conventional laparoscopy, *HAL* hand-assist laparoscopy

Single Institution Studies for Robotic Colectomy

Several single site reports have demonstrated the safety and feasibility of the robotic platform for colectomies [17–25].

DeNoto et al. reported no complications and no conversions for 11 patients who had robotic sigmoid colectomies [17]. D'Annibale described 50 consecutive robotic right colectomies for cancer. This study showed no conversions and reasonable oncologic outcomes to include a disease-free survival of 85 % in stage III patients. This

Table 15.7 Circumferential margins: rectum

	N robot	N lap	+ CRM robot	+ CRM lap	*P* value
Hellan [40]	39		0.0 %		
Patriti [54]	29	27	0.0 %	0	NS
Baik [55]	56	57	7.1 %	8.8 %	NS
Park [56]	41	82	4.9 %	3.7 %	NS
Pigazzi [46]	143		0.7 %		
Bianchi [57]	25	25	0.0 %	4	NS
Kim NK [62]	100	100	3	2	NS
Baek [63]	41	41	2.4	4.9	NS
deSousa [61]	36	51	0	6.5	NS
Kwak [66]	59	59	1.7 %	0	NS
Park [68]	52	123	4.5	5.8	NS
Kim YW [64]	62	147	3.2	2.7	NS
Kang [60]	104	97	4.2 %	6.7	NS
Park SY [59]	40	40	7.5	5	NS
D'Annibale [58]	50	50	0.0 %	12	**0.02**
Kim [85]	48		0.0 %		
Ielpo [69]	56	87	3.6	2.3	NS
Kuo [70]	36	28	12.5	16.7	NS

Table 15.8 Complications: rectum

	N robot	N lap	Morbidity robot	Morbidity lap	*P* value	Leak robot	Leak lap	*P* value
Patriti [54]	29	37	29.2	18.7	NS	6.8	2.7	NS
Baik [55]	56	57	5.4	19.3	**0.025**	1.8	7	
Park [56]	41	82	29.3	23.2	NS	9.7	7.3	NS
Bianchi [57]	25	25	16	24	NS	4	8	
Baek [63]	41	41				8.6	2.9	0.616
Kwak [66]	58	59				13.6	10.2	0.609
Park [68]	52	123	19.2	12.2	0.229	9.6	5.6	NS
Kim YW [64]	62	147	12.9	17.7	0.4	6.6	10.9	NS
Kang [60]	104	97	20.6	27.9	0.3	7.3	10.8	NS
Park SY [59]	40	40	15	12.5	0.745	7.5	5.0	NS
D'Annibale [58]	50	50	10	22	0.104	10	14	0.998
Kuo [70]	36	28	25	32	NS			
Ielpo [69]	56	87	26.8	23	0.61	9.7	4.5	0.35

study also demonstrated the feasibility of the intracorporeal anastomosis [18]. Abodeely et al. evaluated 48 patients with various colorectal diseases to include ten with low rectal cancers and 22 with diverticulitis. There were no conversions and one anastomotic leak. Mean hospital LOS was 5.4 days. Oncologic margins were acceptable and short-term outcomes were reasonable [19]. Luca et al. studied 55 consecu-

Table 15.9 Complications: colon

	N robot	N lap	Morbidity robot	Morbidity lap	*P* value	Leak robot	Leak lap	*P* value
D'Annibale [27]	53	53	7.5	17				
deSousa [31]	40	135	20	20.7	0.919			
Bertani [71]	34	30	18	13	NS	3	3	NS
Luca [72]	33	102	8					
Tyler [33]	160	2423	21.7	21.6	0.992			
Lim [36]	34	146	10.3	5.9	0.281	0	1.4	NS
Casillas [37]	146	200	14	29	**0.03**	0	5	0.1
Trastulli [38]	102	94 EC	22.5	22.3	0.955	2.9	2.1	0.845
		40 IC	22.5	20	NS	2.9	0	NS
Trinh [39]	15	25	20	36	0.457	1	0	NS
Tam [89]	409	1511	14.8	10.7	0.22	2.1	1.0	0.26
	409	815	14.8	9.8	0.12	2.1	2.4	0.86
Ielpo [69]	56	87	26.8	23	0.61	9.7	4.5	0.35

tive robotic procedures for rectal and left colon cancer. Complication rates and oncologic outcomes were acceptable. Anastomotic leak rate was 12.7 % [20]. Huettner et al. reported on 102 consecutive colectomies for benign and malignant neoplasia and diverticulitis. There were 59 right colectomies and 43 sigmoid resections. Conversion rate was 8.8 %. Mean hospital LOS was 3 days. Anastomotic leak rate was 0.98 % [21]. Ragupathi et al. presented 24 patients with diverticulitis who had anterior resection. There were no conversions and the complication rate was 12.5 % with no anastomotic leaks. Mean hospital LOS was 3.4 days [22].

Park et al. published their experience with robotic right colectomy with intracorporeal anastomosis for 15 patients with colon cancer. There were no conversions and oncologic results were acceptable [23]. Trastulli et al. also reported on the feasibility of robotic right colectomy with intracorporeal anastomosis for colon cancer in 20 consecutive patients. There were no conversions and margins were good [24]. Eriksen et al. performed a retrospective review of 223 robotic colon and rectal procedures for a variety of diagnoses. Conversion to open was required in 9 % of patients. Complication rates were acceptable. They found that operative time decreased with experience [25].

Retrospective and Comparative Studies for Robotic Colectomy

With some exceptions, retrospective and case-matched comparison trials have demonstrated that robotic colectomy outcomes are similar to the laparoscopic approach for diseases of the colon [26–39]. Several studies have shown no difference in estimated blood loss (EBL), R0 resection, lymph node harvest, complications, reoperation, LOS, and operative mortality. Operative time is longer and institutional costs are higher for the robotic approach. Incisional hernia rates are less for robotic right colectomies because when compared to the extracorporeal anastomosis, the technically less demanding robotic intracorporeal anastomosis allows the specimen extraction site to be away from the midline where the incisional hernia rate is highest [34, 35]. Three studies showed shorter recovery times as measured by quicker return of gastrointestinal activity or shorter hospital LOS for the robotic group and one study showed fewer conversions for robotic right colectomies [35–38].

In one of the earliest robotic colorectal surgery reports, Delaney et al. compared six robotic and six laparoscopic procedures for various benign and malignant diagnoses. Though the robotic approach was safe in their experience, they expressed concerns about the added cost of the robotic approach [26]. D'Annibale compared 53 robotic with 53 laparoscopic colorectal procedures for various indications and found the robotic approach to be particularly advantageous for splenic flexure mobilization, dissection in a narrow pelvis, identification of the pelvic nerves, and in the construction of handsewn anastomoses. There were no differences between robotic and laparoscopic groups with respect to operative time, lymph node harvest, and hospital LOS [27]. Anvari et al. compared ten patients who had robotic colorectal surgery with the Zeus system with ten laparoscopic colorectal procedures for similar indications. There were no intraoperative complications or conversions in the robotic group. Morbidity and hospital LOS for the robotic group were comparable to the laparoscopic group. Operative times for the robotic group decreased after the first four cases [28].

Rawlings et al. compared 30 robotic and 27 laparoscopic colectomies and performed subgroup analysis of right- and left-sided procedures. Robotic right colectomies were longer because these procedures included an intracorporeal anastomosis, whereas the laparoscopic counterparts were all extracorporeal anastomoses. Operative times and costs were higher for the robotic group [29]. Spinoglio et al. compared their first 50 robotic colorectal procedures with 161 laparoscopic procedures, mostly for malignant neoplasia. Oncologic results were comparable and operative time was increased for the robot group [30]. deSousa et al. compared 40 robotic and 135 laparoscopic right hemicolectomies for various benign and malignant diagnoses. All anastomoses were done extracorporeal. Conversion rates and outcomes were similar for both procedures. Operative time and institutional costs were higher with the robotic approach [31].

Deutsch et al. conducted a retrospective review of 79 robotic and 171 laparoscopic colectomies for benign and malignant disease with subgroup analysis of the right and left side. Hospital LOS and other outcome measures were similar. Robotic operative times were longer for the left colectomy group but not for the right colectomy group [32]. In a review of the 2008–2009 National Inpatient Sample, Tyler et al. compared 160 robotic cases with 2423 laparoscopic cases of diverse benign and malignant indications. Complication rates and hospital LOS were similar for both groups. Robotic surgery was associated with more postoperative infections, fistulas, and thromboembolic events, and less pneumonia, ileus, and anastomotic complications. The robotic option was associated with higher institutional costs [33].

Morpurgo et al. compared 48 robotic right hemicolectomies with intracorporeal anastomosis to 48 laparoscopic right hemicolectomies with extracorporeal anastomosis. Operative results were similar in both groups while the robotic approach took longer. Hospital LOS was shorter for the robotic group. Anastomotic complications and incisional hernias were more common in the laparoscopic group [35]. Lim compared 30 robotic and 146 laparoscopic colectomies for sigmoid colon cancer. Clinical and oncologic outcomes were similar in both groups. The robotic mean operative time was longer [36].

Casillas et al. compared 200 laparoscopic and 146 robotic colorectal operations for benign and malignant disease. Robotic surgery was associated with longer operating times but shorter LOS for left colectomies and fewer conversions to open for right colectomies. There were also fewer postoperative complications for robotic abdominal operations to include ileus and anastomotic leaks [37]. Trastulli et al. did a retrospective review of patients who had robotic right colectomy with intracorporeal anastomosis ($n=102$), laparoscopic right colectomy with extracorporeal anastomosis ($n=94$), and laparoscopic right colectomy with intracorporeal anastomosis ($n=40$). There were no differences in conversion rates, 30-day morbidity and mortality, lymph node harvest, and other oncologic parameters. Robotic right colectomy had better recovery outcomes than laparoscopic right colectomy with extracorporeal anastomosis, and shorter time to first flatus without a difference in hospital LOS when compared to laparoscopic right colectomy with intracorporeal anastomosis. These authors concluded that the robotic advantage is due to the intracorporeal anastomosis [38]. Trinh et al. compared 15 robotic with 25 laparoscopic colorectal cases in a small series. There was no difference in blood loss, operative times, lymph node harvest, and hospital LOS between groups [39].

Studies Evaluating the Robotic Approach for Rectal Resection

Several single institution and multicenter studies evaluating the role of robotic surgery for cancer of the rectum have demonstrated safety and feasibility of the robotic approach [40–52].

Hellan et al. analyzed 39 consecutive patients who had robotic total mesorectal excision (TME) for rectal cancer. The conversion rate was 2.6 % and the anastomotic leak rate was 12.1 %. All had negative circumferential margins. The authors concluded that the robotic approach was safe and could be conducted according to sound oncologic principles [40]. Choi et al. reported 13 patients who underwent robotic colorectal surgery with transanal or transvaginal retrieval of specimens. Eleven patients had low anterior resection and two patients had high anterior resection. Their outcomes were reasonable with a completely intracorporeal resection and anastomosis, and without a transabdominal specimen extraction site [41]. Baek et al. analyzed 64 consecutive patients with stage I–III rectal cancer. The conversion rate was 9.4 % and oncologic parameters to include lymph node harvest, distal margins, and circumferential margins were all adequate. Early oncologic outcomes at 3 years were similar to open TME [42]. Choi et al. reviewed 50 consecutive robotic TME for rectal cancer. Mean operative time was 5 h. Complication rate was 18 %, and 8.3 % had anastomotic leaks. Mean lymph node harvest was 20.6 lymph nodes [43]. deSousa et al. performed a retrospective review of 44 robotic TME for rectal cancer. Most patients were obese and 89 % of these neoplasms were in the low or mid rectum. The conversion rate was 4.5 % and outcomes were favorable [44]. Park et al. reviewed 45 patients who had a totally robotic technique for rectal cancer. The conversion rate was 2.2 % and the complication rate was 11.1 % [45]. Pigazzi et al. reviewed 143 robotic procedures for rectal cancer in three centers. The conversion rate was 4.9 %. They concluded that oncologic outcomes compared favorably with open resection [46].

Koh reported 21 patients who underwent robotic rectal resection for cancer. Postoperative morbidity occurred in 14.3 %. There were no conversions and average LOS was 6.4 days. Mean lymph node harvest was 17.8 [47]. Leong et al. evaluated 29 patients with rectal cancer who underwent robotic TME with intersphincteric resection. Median distance of the tumor from the anal verge was 3 cm. Lymph node harvest and oncologic margins were acceptable. There were no conversions [48]. In a study evaluating the robotic surgery learning curve, Bokhari et al. assessed 50 patients who had robotic procedures for benign and malignant rectosigmoid disease. Utilizing the cumulative sum technique, they determined that the learning curve for robotic surgery was 15–25 cases [49]. Zawadzid et al. evaluated 77 consecutive robotic rectal resections for cancer using the hybrid approach, characterized by laparoscopic mobilization of the proximal colon and robotic TME. Sixty-eight were low anterior resections and nine had coloanal anastomoses. A total of 3.9 % had positive circumferential margins. The anastomotic leak rate was 6.4 %. The authors concluded that the hybrid robotic-laparoscopic technique for rectal cancer is a viable method to incorporate robotic training into colorectal practice [50]. In a review of 182 patients who had robotic TME for rectal cancer, Baek et al. separated patients into easy, moderate, and difficult groups based on preoperative MRI pelvimetry. There were no differences between groups with respect to operative time, complications, or oncologic outcomes. The authors concluded that robotic surgery offers comfort for the surgeon and may overcome the challenges with difficult pelvic anatomy [51]. Shiomi et al. described 113 consecutive robotic rectal resections for patients with rectal cancer. There were 82 anterior resections, 23 intersphincteric resections, and eight abdominoperineal resections. Median operative time was 302 min. There were no conversions and outcomes were reasonable [52].

Retrospective and Comparative Studies for Rectal Resection

Case-matched comparisons of robotic and laparoscopic TME for cancer of the rectum have demonstrated results at least comparable to the laparoscopic approach [53–57] with some studies showing an advantage to the robotic platform with respect to conversion [54, 55, 58], recovery time [58, 59], hospital LOS [55, 59, 60], and oncologic parameters [54, 55, 59, 61]. Operative times are longer for the robot in some studies but this difference is not as apparent for TME for low and mid rectal cancers, a lengthy operation by any approach. Minimally invasive surgeons with considerable laparoscopic experience conducted many of the early comparisons of laparoscopic and robotic surgery. The inconsistencies in results and conclusions may be a reflection of this variation in minimally invasive expertise.

Pigazzi et al. compared six consecutive patients who had total mesorectal excision (TME) for rectal cancer with six patients who had TME by the conventional laparoscopic approach. There were no conversions in either group. Operative time and hospital LOS were the same in both groups [53]. Patriti et al. compared 29 patients who had TME for rectal cancer with 37 patients who had the laparoscopic approach. Operative time was shorter for the robotic approach in this study. Conversion rates were lower for the robotic group (0 vs. 18.9 %) and there was a trend in this group toward better disease-free survival [54]. Baik et al. compared 56 robotic low anterior resections for rectal neoplasia with 57 done by conventional laparoscopy. Operative times were the same in both groups. Conversion rates, major complications, and hospital LOS were more favorable in the robotic group when compared to the laparoscopic group. Pathologic mesorectal grading, a reflection of the adequacy of TME and circumferential margins, was better in the robotic group ($p = 0.03$) [55]. Park et al. compared 41 patients who had TME for low rectal cancer with 82 matched patients who underwent laparoscopic TME. A higher percentage of patients had specimen extraction either by transanal or transvaginal techniques in the robotic group (48.4 % robotic vs. 13.4 % laparoscopic). Complication rates were similar between groups as was lymph node harvest, distal margins, and circumferential margins [56]. Bianchi et al. compared 25 robotic TME and 25 laparoscopic TME for low and mid rectal cancers. Median operating time, first bowel movement, median hospital LOS, postoperative complications, median lymph node harvest, distal margins, circumferential margins, and conversions were all similar between the two groups [57].

Kim et al. performed a case-matched comparison of 100 open, 100 laparoscopic, and 100 robotic TME for rectal cancer. The conversion rate was 2 % in the robotic group and 3 % in the laparoscopic group. Operative time was longer for the robotic group. Oncologic margins were the same in all groups, but lymph node harvest was higher in the open than in the laparoscopic and robotic groups. The robotic group was better than laparoscopic and open groups with respect to first flatus, tolerating a soft diet, and hospital LOS. There was no difference in anastomotic leak rates among groups [62]. deSousa et al. compared 36 consecutive robotic rectal resections with 51 consecutive laparoscopic rectal resections. Hand-assisted laparoscopy was used for splenic flexure mobilization in all cases. There were more abdominoperineal resections and more low and mid rectal neoplasms in the robotic group. Operative time was longer for the robotic group. Complications, lymph node harvest, and hospital LOS were comparable. The robotic group had fewer positive circumferential margins but this did not reach statistical significance [61]. Baek et al. compared 41 robotic TME and 41 laparoscopic TME for rectal cancer from a prospectively maintained database. Operative time, conversion rates, and the number of anastomotic leaks were similar, as were oncologic outcomes. Hospitalization costs were higher for the robotic approach but did not reach statistical significance [63].

In another learning curve study of 62 patients who had robotic surgery for rectal cancer, Kim et al. showed that the operative and console times decreased after 20 cases. When comparing these robotic procedures with 147 laparoscopic cases, there was no difference in complications including anastomotic leaks, and no difference in lymph node harvest and oncologic margins during the learning curve period. These authors concluded that an open surgeon may be trained on robotic technology without a long learning curve, even without previous laparoscopic experience [64]. Baek et al. compared 154 robotic and 150 laparoscopic rectal resections for cancer. There were more patients with low rectal neoplasms who had preoperative chemoradiation in the robotic group. Nevertheless, postoperative course and complication rates were similar between the two groups. The robotic approach was associated with higher institutional costs [65].

Kwak et al. retrospectively analyzed 117 robotic and 102 laparoscopic rectal cancer resections over a 2-year period. Lymph node harvest, resection margins, and conversion rates were similar for both groups. Operative time was longer for the robotic group. Short-term local recurrence rates and distant metastases were similar between groups [66]. Patel et al. performed a 3-arm case-matched analysis to include 30 robotic, 30 hand-assisted laparoscopic, and 30 conventional laparoscopic resections of the rectum and rectosigmoid. Complication rates, lymph node harvest, and hospital LOS were similar among all three groups. Operative time for low rectal cancers was comparable for all three groups [67]. Park et al. compared 52 patients who had robotic procedures for rectal cancer with 123 laparoscopic and 88 open procedures. The operative time for the robotic approach was longer. The proportion of patients who had natural orifice (transanal or transvaginal) extraction with intracorporeal anastomosis was higher in the robotic group. Complication rates, lymph node harvest, and margins were the same among the three groups [68].

Kang et al. conducted a case-matched analysis comparing open ($n=165$), laparoscopic ($n=165$), and robotic ($n=165$) rectal resections for rectal cancer. They applied propensity scores to adjust for patient and tumor characteristics and found that some outcomes (time to soft diet and hospital LOS) were more favorable with the robot. Short-term disease-free survival was the same among the three groups. The authors concluded that the robotic approach has advantages over open and laparoscopic surgery for low and mid rectal neoplasms [60]. Park et al. did a study comparing 40 robotic TME with intersphincteric dissection and 40 laparoscopic TME with intersphincteric dissection in patients with rectal cancer. Transabdominal intersphincteric dissection was performed more often with the robotic than the laparoscopic approach. There was no difference in postoperative morbidity and pathologic outcomes. There was a trend toward less blood loss and quicker functional recovery in the robotic group [59]. D'Annibale et al. compared 50 consecutive robotic TME to 50 consecutive laparoscopic TME for rectal cancer. Median operative time was the same in both groups. There were more favorable outcomes with the robotic approach with respect to conversions (0 % vs. 14 %), circumferential margins (5 vs.

12 %), hospital LOS, and voiding and sexual function [58]. Ielpo et al. compared 56 robotic with 87 laparoscopic rectal resections for cancer. The conversion rate was significantly better for the robotic approach for lower rectal cancers (1.8 % vs. 9.2 %, $p = 0.04$). Operative time was longer in the robotic group. There was no difference in hospital LOS, complications, or oncologic outcomes between groups [69]. Kuo et al. retrospectively evaluated the feasibility of robotic intersphincteric resection in 36 patients with low rectal cancer and compared them with 28 patients who had the laparoscopic approach. They found the robotic approach to be safe and feasible and that operating times decreased with experience [70].

Comparisons Between Robotic and Open Colectomy

Bertani et al. compared 45 open, 30 laparoscopic, and 34 robotic colectomies and rectal resections for colorectal cancer. Laparoscopic and robotic approaches had several advantages compared to open groups. The robotic approach was associated with higher institutional costs [71]. Luca et al. compared 33 robotic and 102 open right colectomies for cancer. The robotic anastomoses were constructed in an extracorporeal fashion. Lymph node retrieval and hospital LOS were better with the robotic approach (5 days vs. 8 days) [72].

Comparisons Between Robotic and Open for Rectal Resection

The results of the ACOSOG randomized study comparing open and laparoscopic TME for rectal cancer that showed inferior oncologic parameters for the laparoscopic approach raise the question of the possible need for a randomized trial comparing robotic and open approaches for rectal cancer [6]. However, a proposal for a randomized trial comparing robotic and open TME is unlikely. There are some small case series and comparisons between robotic and open procedures.

Kim et al. did a case-matched comparison of 100 robotic procedures and 100 open procedures for rectal cancer. The distal margin was longer in the robotic group. Complication rates and functional results were comparable between groups [73]. Kim et al. compared 108 patients with rectal cancer who underwent a completely transabdominal robotic intersphincteric resection with 114 patients with rectal cancer who underwent the same procedure by an open approach. Abdominal intersphincteric resection was completed more often in the robotic group than the open group (82.6 % vs. 67.9 %, $p = 0.008$). The two groups had equivalent morbidity, oncologic margins, and lymph node harvest. The robotic group had 2.7-fold less frequent moderate to severe sexual dysfunction when compared to the open group. Fecal incontinence scores were better in the robotic group at 6 and 12 months ($p < 0.05$) [74]. In another study, this same group compared 21 patients who underwent curative abdominoperineal resection for rectal cancer with 27 patients who had the open approach. The robotic group had a similar percentage of cylindrical excision (76 % vs. 70 %, $p=0.75$), better lymph node harvest (20 vs. 16, $p=0.3$), and fewer positive circumferential margins than the open group (0 % vs. 15 %, $p=0.12$). The circumferential margins were also significantly wider in the robotic group (76 mm vs. 25 mm, $p=0.02$) [75].

Meta-analyses and Reviews

Several meta-analyses have now been conducted comparing robotic and laparoscopic colorectal surgery. Most of these studies show advantages for the robotic approach with respect to conversion rates [76, 87–88].

Lin et al. conducted a meta-analysis of eight studies comparing 268 robotic and 393 laparoscopic resections for rectal cancer. The robotic approach resulted in less conversion to open. All other outcomes were the same including operative time [76]. A meta-analysis by Memon et al. assessed seven studies comparing robotic ($n=353$) and laparoscopic ($n=401$) proctectomy for rectal cancer. Again, the robotic approach resulted in fewer conversions. There were no differences in hospital LOS, complications, lymph node harvest, and oncologic margins [77]. In a review and meta-analysis that included 203 robotic and 283 laparoscopic surgeries for rectal cancer, Ortiz-Oshiro et al. found that conversion rates were more favorable for the robotic approach. There was no difference in complications between groups including anastomotic leaks. There were no differences in hospital LOS and oncologic outcomes [78]. In another meta-analysis of 16 studies for benign and malignant colorectal disease, Yang et al. found that the robotic approach to rectal cancer was associated with less blood loss, fewer conversions, longer operating time, and higher costs when compared to the laparoscopic approach [79]. In a comprehensive literature review that included 39 case series or comparative nonrandomized studies of patients undergoing robotic resections for benign and malignant colorectal disease, Antoniou et al. found that robotic right and left colectomies had low conversion rates (1.1 % and 3.8 %, respectively) and acceptable operative morbidity (13.4 % and 15.1 %, respectively). Robotic anterior resection was associated with a low conversion rate (0.4 %), low morbidity (9.7 %), and adequate lymph node harvest (mean 14.3) [80].

In a systematic review of short-term outcomes that included 351 robotic colorectal procedures, Fung et al. found that complication rates were similar, and that operative time and cost were higher for the robotic approach when compared to the laparoscopic approach [81]. Liao et al. performed a meta-analysis of four randomized trials comparing 110 robotic and 116 laparoscopic colorectal surgeries. The robotic approach was associated with significant reduction in estimated blood loss, conversion to open (1.8 % vs. 9.5 %, $p=0.04$), and more favorable time to bowel function recovery. There were no differences in complications rates, hospital LOS, oncologic margins, and lymph node harvest [82]. In a systematic review and meta-analysis of eight nonrandomized studies to include 344 robotic and 510 laparoscopic resections for rectal cancer, Trastulli et al. found that conversion was significantly lower for the robotic group, while there were no differences in operating time, hospital LOS, time to diet, postoperative complications, oncologic margins, and lymph node harvest [83].

In another systematic literature review of 59 articles containing 1635 robotic colorectal resections that included 254 right colectomies, 185 left/sigmoid colectomies, 969 anterior resections, 182 abdominoperineal or intersphincteric resections, 34 unspecified colectomies, and 11 subtotal/total colectomies, Papanikolaou et al. found favorable outcomes for the robotic approach with respect to blood loss, conversion rates, complications, and shorter hospital LOS. Operative time was longer and lymph node harvest was adequate for the robotic approach in this study [84]. A PubMed and Google Scholar search by Kim et al. included 69 publications: 39 case series, 29 comparative series, and one randomized controlled trial. Robotic surgery was associated with comparable short-term outcomes, longer operating time, and higher cost when compared with laparoscopic and open surgery [85].

In a search of electronic databases conducted for a systematic review of laparoscopic and robotic resection for extraperitoneal and intraperitoneal rectal cancer, Scarpinata et al. found that cost and operating time for the robotic approach was higher. There was a higher percentage of low rectal neoplasms with a shorter distance from the tumor to the anal verge in the robotic group. Nevertheless, the conversion rate was lower for the robot even in those who had low rectal tumors, preoperative chemoradiation, and those who were obese. There were also marginally better outcomes with respect to preservation of bladder and sexual function, circumferential margins, and anastomotic leaks, though this favorable comparison for the robot was not statistically significant in this study [86].

In a National Cancer Database comparative analysis of 1182 robotic and 5296 laparoscopic rectal resections for adenocarcinoma, Thirun et al. showed a significantly lower conversion rate with the robotic approach (9.7 % vs. 17.4 %, $p < 0.001$). The authors suggested that this difference in conversion was clinically significant because minimally invasive conversions were associated with worse outcomes with respect to positive circumferential margins (6.9 % vs. 4.8 %, $p = 0.001$), hospital LOS (6 days vs. 5 days, $p < 0.001$), 30-day readmission (8.9 % vs. 7.1 %, $p = 0.04$), 30-day mortality (1.9 % vs. 1.1 %, $p = 0.03$), and time to adjuvant treatment (52 days vs. 47 days, $p = 0.04$) [87]. In a review of 1458 robotic (559 colectomy) and 165,332 laparoscopic cases in the New York Statewide Planning and Research Cooperative System database, Zhu et al. demonstrated that complications (22.9 % vs. 32.3 %, $p < 0.0001$) and hospital LOS (5.11 days vs. 6.76 days, $p < 0.001$) were less with the robotic platform [88].

Tam et al. did a propensity score analysis of a protocol-driven, externally audited, validated large regional database composed of 64 Michigan hospitals with diverse minimally invasive expertise. There were 1511 laparoscopic, 815 hand-assisted laparoscopic, and 409 robotic colorectal operations for benign and malignant disease that met inclusion criteria. This study demonstrated that conversion rates were lower for robotic when compared to both laparoscopic approaches, and this was significant for proctectomies (7.8 % vs. 21.2 %, $p < 0.001$). They also found that hospital LOS was significantly shorter for robotic colectomies (4.00 days, 95 % CI 3.63–4.40) when compared to laparoscopic (4.41 days, 95 % CI 4.17–4.66; $p = 0.04$) and hand-assisted laparoscopic cases (4.44 days, 95 % CI 4.13–4.78; $p = 0.008$) [89]. In an analysis of the National Surgical Quality Improvement Program (NSQIP) database, Bhama et al. compared 7790 laparoscopic and 299 robotic colectomies, and 3057 laparoscopic and 331 robotic proctectomies. They found that conversion rates were significantly better with the robot in the pelvis (10.0 % vs. 13.7 %, $p = 0.01$) and that the risk factors for conversion were BMI > 30, ASA Class III and IV, disseminated cancer, and anemia. Hospital LOS was significantly shorter for both colectomies (4.3 vs. 5.3 days, $p < 0.001$) and proctectomies (4.5 vs. 5.3 days, $p < 0.001$) with the robotic approach [90].

Randomized Controlled Trials

Comparing Laparoscopic and Open

Several randomized trials comparing open and laparoscopic colorectal surgery preceded randomized trials that included the robotic approach. In the Clinical Outcomes of Surgical Therapy Study Group (COST) trial, 872 patients with colon cancer were randomized to either open ($n = 428$) or laparoscopic ($n = 435$) arms. Complications, readmissions, and oncologic outcomes were similar between the two groups. Operative times were longer in the laparoscopic group (150 min vs. 95 min, $p < 0.001$). Hospital LOS was shorter in the laparoscopic group (5 days vs. 6 days, $p < 0.001$). The conversion rate in the laparoscopic group was 21 % [1].

The United Kingdom Medical Research Council Conventional versus Laparoscopic-Assisted Surgery in Colorectal Cancer (UK MRC CLASICC) Trial Group conducted a randomized controlled study designed to compare laparoscopic-assisted and open resection for colorectal cancer. Unlike the COST trial, this study included patients with rectal cancer. There were 526 patients randomized to the laparoscopic arm, and 268 to the open arm. This group reported higher rates of positive circumferential margins for laparoscopic rectal resection (12 % vs. 6 %) compared to open [2]. This same group subsequently reported 3- and 5-year follow-up reports revealing that the higher incidence of positive circumferential margins in the laparoscopic group did not translate into increased local recurrence (laparoscopic 9.7 % vs. open 10.1 %). There was also no significant difference in overall survival and disease-free survival. Conversion to open in this trial was 25 % for cancer of the colon and 34 % for cancer of the rectum, and conversion decreased overall from 38 % in year 1 to 16 % in year 6. Converted cases in the colon cancer group were associated with higher morbidity (laparoscopic 28 % vs. laparoscopic converted 45 %), higher mortality (laparoscopic 1 % vs. laparoscopic converted 9 %), and decreased disease-free and overall survival [3, 4, 6].

The more recent COlorectal cancer Laparoscopic or Open Resection II (COLOR II) Study Group trial was designed to address the laparoscopic learning curve that may have skewed results in the UK MRC CLASICC trial in favor of the open group. In this study, 1103 patients with rectal cancer within 15 cm of the anal verge were randomized to laparoscopic ($n=739$) and open ($n=364$) groups. Macroscopic resection "completeness," and circumferential and distal resection margins were the same in both groups. The laparoscopic group had less blood loss, shorter time to bowel movements, shorter time to tolerating liquids, and shorter hospital LOS [5]. The UK MRC CLASICC trial required investigators to have performed 20 cases prior to study entry. Recent evidence suggests that the laparoscopic learning curve may be closer to 50–75 cases [91]. Some of the advantages for laparoscopy compared to open in the UK MRC CLASICC study—less blood loss, decreased postoperative pain, and shorter hospital LOS—were also advantages in the COLOR II trial [92]. In addition, the COLOR II trial demonstrated that laparoscopic circumferential margins were as good as open surgery (10 % vs. 10 %) and better for low rectal cancers. However, the complete TME rate was 4 % lower in the laparoscopic group compared to the open group (88 % vs. 92 %). The prominent laparoscopic expertise of the COLOR II trial compared to the UK MRC CLASICC trial did not eliminate long operative times – average was 240 min with a range of 180–300 min. And though conversion to open decreased from 29 % in the UK MRC CLASICC trial to 17 % in the COLOR II trial, this is still significantly higher than conversion with robotic surgery for rectal cancer (0–10.0 %) [86, 89, 90].

Arezzo et al. performed a review and meta-analysis of 27 studies comparing laparoscopic and open surgery for rectal cancer that included 10,861 patients. Eight of these studies were randomized controlled trials that included 2659 patients. Subgroup analysis showed that circumferential margins were the same in patients with extraperitoneal rectal cancers (lap 10.3 %, open 11.6 %). There were no differences in R0 resections, distal margins, mesorectal grading, and 5-year local recurrence (lap 3.5 % vs. open 5.6 %). These authors concluded that short-term oncologic laparoscopic outcomes appeared to be equivalent to open surgery for rectal cancer [93].

In a phase III randomized trial to determine noninferiority of the laparoscopic approach, Fleshman et al. compared laparoscopic ($n=240$) and open ($n=222$) TME for clinical stage II–III rectal cancer within 12 cm of the anal verge. The primary outcome was TME efficacy as determined by a composite evaluation consisting of circumferential margin > 1 mm, negative distal margin, and TME completeness. Sphincter preservation by low anterior resection was accomplished in 76.7 % of cases and abdominoperineal resection was performed in 23.3 % of cases. The conversion rate for the laparoscopic group was 11.3 %. Hospital LOS, complications, and readmissions were the same in both groups. Successful TME as measured by circumferential and distal margins, and mesorectal grading was not considered noninferior to open by the primary outcome definition (86.9 % vs. 81.7 %, $p=0.16$). The authors emphasized that most of the participating surgeons in this trial also participated in the COST trial for laparoscopic treatment of colon cancer and are some of the most experienced laparoscopic surgeons in the world [6]. Other authors have also expressed concern about circumferential margins with laparoscopic TME and have suggested that the enhanced imaging, more effective traction and counter-traction, and more precise microdissection of robotic surgery may potentially decrease the risk of positive circumferential margins [54, 56, 62, 86].

The decreased hospital LOS and earlier recovery for the laparoscopic approach when compared to the open approach reported in the COST trial for colon cancer was not apparent in the ACOSOG trial for rectal cancer. Operative times were longer in the laparoscopic group and rectal perforations were more frequent. Whether or not the positive circumferential margins in the ACOSOG trial will translate into worse oncologic outcomes awaits analysis of mature data [6]. These randomized trials suggest that laparoscopic resection for rectal cancer may be safe and feasible, but oncologic outcomes are inconsistently reported to date and still largely undetermined.

Comparing Laparoscopic and Robotic

The first randomized trial comparing robotic and laparoscopic colorectal surgery was a pilot study reported by Baik et al. This trial compared 18 robotic and 18 laparoscopic low anterior resections for rectal cancer and showed a more favorable hospital LOS for the robotic group (robotic-assisted: 6.9 ± 1.3 days; standard laparoscopic: 8.7 ± 1.3 days, $p < 0.001$). The authors attributed the decreased hospital LOS for the robotic group to less surgical trauma. Conversion rates, operating times, and complications were similar between the two groups. Oncologic specimen quality of the robotic group was acceptable and mesorectal grading was better for the robotic group [13]. Jiménez et al. randomized 56 patients with colorectal cancer to robotic and laparoscopic groups. Most neoplasms (78.5 %) were greater than 15 cm proximal to the anal verge in both groups. Conversion rates, hospital LOS, and complications were similar between groups. Operative time was longer with the robotic approach. The distal margin of resection was greater in the robotic group [14]. Park et al. randomized 70 patients with right colon cancer to robotic ($n = 35$) versus laparoscopic ($n = 35$) right colectomy. Resection margins, lymph node harvest, postoperative pain scores, postoperative complications, and hospital LOS were the same in both groups. There were no conversions in either group. Costs were higher in the robotic group [15].

Ongoing randomized controlled trials include the Randomized Trial on Robotic Assisted Resection for Rectal Cancer at the University of Hong Kong. This trial is designed to prospectively randomize 98 patients to laparoscopic and robotic arms for resection of tumors within 15 cm of the anal verge. The primary outcome is bladder and sexual function. Secondary outcomes include perioperative outcomes, quality of life, cost, quality of the resected specimen, and local recurrence rates. The estimated completion date for the primary outcome is December 2014, but the site on clinicaltrials.gov has not been verified since May 2010, and the recruitment status for this trial is unknown [94].

There are currently two randomized trials comparing the laparoscopic and robotic approach to TME for low and mid rectal cancers in South Korea. The first is the Efficacy Study of Robotic Surgery for Rectal Cancer/National Cancer Center phase

II trial that is designed to randomize 146 patients with rectal cancer within 9 cm of the anal verge to laparoscopic and robotic arms. The primary endpoint is TME quality. Secondary outcomes include 30-day perioperative complications, sexual and urinary function, quality of life, anorectal function, and 3-year disease-free survival. The estimated study completion date for the primary outcome is December 2014 [95]. The second trial is the COLRAR study at Kyungpook National University in South Korea. This trial was designed to prospectively randomize 540 patients to laparoscopic and robotic arms for TME for low and mid rectal cancers within 10 cm of the anal verge. Surgeons must have performed 50 lap and 50 robotic cases to be eligible for participation. The primary outcome is surgical quality via pathologic examination. Photo and video documentation was performed for each case. Secondary outcomes include 3- and 5-year disease-free and overall survival, pelvic autonomic nerve preservation, short-term morbidity, lymph node harvest, local recurrence, and surgical blood loss. The estimated study completion date is December 2015 [96].

The *RO*botic versus *LA*paroscopic *R*esection for *R*ectal Cancer (ROLARR) study was designed to address the high laparoscopic conversion rates in previous rectal cancer trials and the associated increased morbidity and mortality, as well as the compromised circumferential margins depicted in the UK MRC CLASICC laparoscopic versus open TME trial [16]. The quality of the macroscopic specimen provided by total mesorectal excision is a predictor of prognosis and the ability to preserve autonomic nerves thereby decreasing the risk for sexual and urinary dysfunction [97]. The results of this trial were recently reported at the 2015 American Society of Colon and Rectal Surgeons Annual Meeting. Forty experienced surgeons in ten countries randomized 471 patients to laparoscopic (234) or robotic (237) TME for rectal cancer. Forty-four percent of the laparoscopic group and 46 % of the robotic group received neoadjuvant chemoradiation. The primary outcome was conversion to open and there was no significant difference between the two groups (laparoscopic 12.2 % vs. robotic 8.1 %, $p=0.158$). However, subset analysis revealed a possible advantage to the robotic platform for men (laparoscopic 16.0 % vs. robotic 8.7 %), for those who undergo low anterior resection (laparoscopic 13.3 % vs. robotic 7.2 %), and those who are obese (laparoscopic 27.8 % vs. robotic 18.9 %). Mean lymph node yield was adequate in both groups (laparoscopic 24.1, robotic 23.2). TME grading and circumferential margin positivity (laparoscopic 6.3 %, robotic 5.1 %) were the same in both groups. There was no difference in 30-day complications (laparoscopic 31.7 %, robotic 33.1 %) and 30-day mortality (laparoscopic 0.9 %, robotic 0.8 %). Oncologic outcomes with respect to local recurrence, overall survival, and disease-free survival await maturation of study data [16].

Summary

The emphasis on randomized trials to date has been rectal cancer because conversion and circumferential margins are thought to be more significant issues in the narrow pelvis. Data for oncologic outcomes as measured by local recurrence, disease-free survival, and overall survival are limited because the robotic approach is relatively recent compared to laparoscopy in the management of rectal cancer. Potential oncologic outcomes as measured by lymph node harvest, distal resection margins, and circumferential resection margins have not been statistically different in laparoscopic versus robotic comparisons to date. However, the large UK MRC CLASICC and ACOSOG randomized trials comparing laparoscopic and open TME have raised concerns about circumferential margins with the laparoscopic approach.

The robotic platform may be particularly advantageous for those who are men, obese, have had preoperative chemoradiation, and have low to mid rectal neoplasms requiring TME. Whether or not the enhanced imaging, articulating instruments, surgeon control of camera and 3rd arm, and ergonomic advantages that characterize the robotic approach and provide easier retraction and more precise movements at the pelvic sidewalls will translate into better circumferential margins and impact oncologic outcomes will require further large randomized trials to include the robotic approach. The ROLARR study was the first to address these oncologic questions in a large randomized trial comparing robotic and laparoscopic TME.

Related Issues

Conversions

Though some comparative studies show no difference in conversion between the laparoscopic and robotic approaches, the large randomized trials comparing laparoscopic and open TME demonstrate high conversion rates for laparoscopy. Conversion rates for TME vary from 0 to 34 % for laparoscopy and 0 to 10.0 % for the robotic approach [9, 13, 16, 18, 54, 57, 62, 89, 90]. The limited space deep in the pelvis and large tumors make minimally invasive surgery for rectal cancer challenging. Halibi et al. reported that the robotic approach was associated with a 59 % decrease in conversion for colonic procedures and a 90 % reduction in conversion for rectal procedures when compared with the laparoscopic approach [9]. Patriti et al. reported a 19 % conversion rate for laparoscopy compared to no conversions with the robot [54]. Large regional and national protocol-driven, quality-centered, externally audited database analyses have shown significant advantages for the robot for conversion when compared to the laparoscopic approach [89, 90].

Predictors of conversion, and especially surgeon factors as contributors to conversion, warrant further study. The morbidity and impact of conversion to open on oncologic outcomes should also be the subject of further study. MRC-CLASICC data revealed higher morbidity and mortality rates associated with laparoscopic cases that were converted to open operations. This increased morbidity may be related to more advanced cancers requiring conversion, but the contribution of conversion-associated increased operative time, increased technical difficulty, and the need for a laparotomy wound in converted cases should also be evaluated [2, 98].

Other factors for conversion may be related to communication with the assistant controlling the camera and 3rd arm for fixed retraction, physical space limitations at the bedside, frequent correction of assistant tremor or off-center drift, frequent lens cleaning, and other issues that affect primary surgeon concentration and surgeon fatigue. It is possible that surgeon fatigue could impact conversion rates and outcomes. Surgeon fatigue, and neck and back ailments have not been adequately analyzed in randomized trials and may be a pertinent subject for future study. Scales for the evaluation of surgeon fatigue are currently being developed [62].

Learning Curve

Literature to date evaluating robotic learning curves is largely from authors with considerable laparoscopic expertise, making generalized comparisons problematic. It has been estimated that the learning phase for robotic rectal and rectosigmoid resections is 15–32 cases as compared to 50–70 cases for conventional laparoscopy [25, 99–101]. In a study comparing laparoscopic and robotic learning curves for an open surgeon starting laparoscopic and robotic low anterior resections for the first time simultaneously, it was found that robotic low anterior resection operative times became less than laparoscopy after the first 41 cases. Outcomes were acceptable and not significantly different between laparoscopic and robotic groups [102]. In an effort to more meaningfully estimate learning curves, some authors have utilized the cumulative sum analysis (CUSUM) approach. One study identified three phases in the learning curve by this approach: an initial learning curve phase consisting of 15 cases, a plateau phase characterized by familiarity with the console and increasing competence, and a 3rd phase where skill sets improve to the point of scheduling more challenging cases. The learning curve in this study was achieved after 15–25 cases [49].

Another study used operative times, conversions, perioperative complications, and microscopic margins as variables in a risk-adjusted CUSUM model to determine the learning curve for robotic TME for rectal cancer. These authors found that the learning curve has the greatest effect on the first 32 cases [103]. By comparing a surgeon with little (<30 cases) laparoscopic background with a more experienced laparoscopic surgeon (>300 cases) both starting the robotic approach for the first time, Kim et al. showed that robotic outcomes were equivalent and laparoscopy is not a necessary prelude to robotic surgery [25]. Others have shown that increasing surgeon volumes are associated with shorter hospital LOS, fewer complications, and lower costs [104].

A systematic review of learning curves showed that literature to date most commonly utilizes operative times and conversions as learning curve parameters. These data points may not be entirely accurate learning curve predictors because experienced surgeons beyond their learning curves may proceed to more challenging cases that take longer and be more likely to convert to open. These authors suggest that future studies should employ a multidimensional assessment of technical skills thought to be indicators of satisfactory outcomes, such as the 3-phase CUSUM model, to evaluate robotic learning curves in the clinical setting [100, 101].

Sexual and Urinary Dysfunction

Early reports comparing laparoscopic and open rectal resection revealed impaired bladder and sexual function for the laparoscopic approach [105–108]. The UK MRC CLASICC randomized trail comparing laparoscopic and open techniques revealed sexual dysfunction in 41 % of men after laparoscopic rectal cancer surgery compared to 23 % for open rectal cancer surgery. Though this difference was not statistically significant, the authors recognized the trend toward compromised sexual function with the laparoscopic approach [107]. The enhanced robotic image may allow better visualization of autonomic nerves than the laparoscopic image or the naked eye in open surgery. The surgeon-controlled steady camera platform and steady robotic 3rd arm for fixed retraction may allow more precise traction-counter traction dissection than is possible with laparoscopic and open techniques [62]. Several studies have been completed or are ongoing to address the impact these advantages potentially have on other important outcomes.

In a comparative study of voiding and sexual function after laparoscopic (69 patients) and robotic (30 patients) TME for rectal cancer, Kim et al. found that the recovery from impaired voiding function was shorter for the robotic (3 months) than the laparoscopic (6 months) approach. Sexual function as measured by the International Index of Erectile Function (IIEF) also recovered quicker in the robotic group than in the laparoscopic group (6 months vs. 12 months) [62].

Broholm et al. reported a systematic Pubmed, Embase, and Cochrane Library literature review of studies investigating urogenital function after robotic rectal cancer surgery. The outcomes of interest in this study were urologic and sexual function as measured by International Prostate Symptom Score (IPSS), IIEF, and the Female Sexual Function Index (FSFI). In this analysis of four studies that included 152 robotic and 161 laparoscopic patients, IPSS and IIEF scores were better after robotic than after laparoscopic surgery [109]. In a prospective study of 74 patients undergoing robotic TME for rectal cancer, Luca et al. showed that sexual function decreased in men and women significantly 1 month after surgery. However, erectile function in men, and arousal and general satisfaction in women increased progressively to the point of being comparable to preoperative status after 1 year [110].

Park et al. evaluated urinary and sexual dysfunction in a case-matched series comparing robotic TME (32 patients) with laparoscopic TME (32 patients). These investigators found that the IPSS score did not differ between groups at any time of measurement, but that the interval decrease in the IIEF-5 score was significantly lower in the robotic group at 6 months, thereby revealing earlier restoration of erectile function in the robotic group [111]. D'Annibale et al. compared 50 robotic and 50 laparoscopic TME for rectal cancer and measured IPSS and IIEF along with several other outcomes. Erectile function was restored completely at 1 year in the robotic group and partially in the laparoscopic group [58]. Kim et al. compared 39 patients who underwent laparoscopic TME with 30 who underwent robotic TME for rectal cancer. Recovery of urinary function took 6 months for the laparoscopic group and only 3 months for the robotic group. Changes in IPSS scores were significantly different between groups at 3 months ($p = 0.036$). There was a significant difference in change in erectile function and sexual desire at 3 months in favor of the robotic approach [112].

The ROLARR trial that randomized patients with rectal cancer to laparoscopic versus robotic TME includes bladder and sexual function as secondary outcomes. The results of this trial may add perspective to the comparative studies to date. Future studies will be needed, especially with future upgrades in minimally invasive technology that may make TME dissection more precise with resultant improvement in autonomic nerve function preservation.

Intracorporeal Anastomosis and Incisional Hernias

A minimally invasive platform that allows facile suturing offers several potential advantages. Because of the challenges of laparoscopic suturing, most laparoscopic right colectomies are performed by mobilization of the ileum and colon, and then extraction of these structures through a midline incision where the specimen is resected. An extracorporeal anastomosis is then performed by standard open techniques. In comparison, the robotic articulated instruments with wristed movements and 7 degrees of freedom allow a far less challenging intracorporeal anastomosis with suturing. Because the specimen does not have to be extracted prior to the anastomosis, there is potentially less need for transverse colon mobilization and less mesenteric stretching with less mesenteric trauma and bleeding. This technical advantage may potentially lead to less ileus, shorter incisions, and fewer incisional hernias because the extraction incision after intracorporeal resection and anastomosis can be at any location away from the midline or through a natural orifice.

Several studies to date have demonstrated the robotic advantage for an intracorporeal anastomosis after right hemicolectomy [18, 23, 24, 29, 35, 38]. In a study comparing 48 laparoscopic right hemicolectomies with extracorporeal anastomosis and 48 robotic right hemicolectomies with intracorporeal anastomosis, there were fewer incisional hernias and anastomotic complications in the robotic intracorporeal group ($p = 0.05$) [35].

Laparoscopic suturing in the pelvis is an even greater challenge. The ability to extract colectomy and TME specimens by transanal or transvaginal routes may also result in fewer incisional hernias [41, 56, 68]. Robotic transanal approaches to TME make these avenues more realistic considerations and are already the subject of further study.

Minimally Invasive Single Incision Surgery

Single-incision laparoscopic surgery has been shown to be feasible for some colorectal procedures including right hemicolectomies [113]. This minimally invasive option is also currently under evaluation for total mesorectal excision from a combined transabdominal and transanal approach [114]. The evolution of transanal minimally invasive surgery (TAMIS) for low and midrectal neoplasms paved the way for this approach. Limitations in imaging, in-line instrumentation, and working space at the operating table make laparoscopic single-incision surgery challenging, and the penetrance of SILS into colorectal surgery practice has been slow [115]. The ergonomic feasibility of the robotic platform makes it ideally suited for evaluation of the role of robotics for these advanced colorectal procedures.

Early experiences with single-incision robotic surgery were reported by Ostrowitz et al. and Raguopathi [116, 117]. These authors addressed issues with pneumoperitoneum and utilizing robotic instruments to their advantage by crossing arms and reassigning control at the console to allow better angles than could be achieved laparoscopically. The advent of robotic single-incision instruments made this platform more feasible to robotic surgeons.

Spinoglio et al. reported three robotic single-site right colectomies through a suprapubic incision. Two of these patients had an intracorporeal anastomosis. All three patients were discharged within 5 days. Oncologic principles were adhered to and there were no complications [118]. Lim et al. performed robotic single-incision anterior resection on 22 patients with sigmoid colon cancer. Their technique included a transumbilical incision, an access port composed of an Alexis wound protector and a surgical glove, and three robotic arms to include a 30° lens. There was one conversion to multiport surgery. Median operating time was 167.5 min and median incision length was 4.7 cm. Oncologic resection parameters, postoperative pain scores, and hospital LOS were all acceptable [119].

Juo et al. performed a retrospective review of 59 patients who underwent single-incision robotic colectomy for a variety of colorectal diseases. There were 31 right hemicolectomies, 20 sigmoid colectomies, five left hemicolectomies, two low anterior resections, and one total abdominal colectomy. Conversion rates were 6.8 % to open, 5.1 % to multiport robotic, and 1.7 % to single-port laparoscopic procedures. Complications occurred in 27.1 % of cases and were higher in converted cases. Intra-abdominal adhesions and BMI were risk factors for conversions and complications [120]. These authors also reported a robotic single-incision total colectomy. There was minimal blood loss and this patient was discharged on postoperative day 4 without complications. The procedure took 227 min [121].

Transanal Approach to Rectal Neoplasia

The transabdominal approach to rectal neoplasia is challenging by any method, especially in a narrow pelvis, and investigators have sought to develop ergonomically more feasible approaches to this disease, while maintaining or improving clinical and oncologic outcomes. Transanal minimally invasive surgery (TAMIS) is a laparoscopic approach to transanal excision of early rectal neoplasms and has been shown to be safe and feasible [122–124]. The "down to up" transanal approach has also been described and developed for total mesorectal excision of rectal neoplasms. At this time, this procedure is typically done with laparoscopic transabdominal mobilization of the proximal colon and assistance with the proximal part of the TME, though a completely transanal natural orifice approach has been described [125]. The transanal laparoscopic component of these operations has the same limitations as conventional laparoscopic TME from the abdominal approach with respect to rigid in-line instruments, nonadvantageous angles to the pelvic sidewalls, and the difficulty with suturing a defect after excision.

The robotic version of these operations is currently under development in an effort to take advantage of superior imaging, and articulating and wristed instruments. The transanal approach to mid and low rectal neoplasms is feasible though docking is challenging. FDA approval of a single-incision robotic system for the transanal approach has the potential to make this platform the procedure of choice, in light of the robotic imaging, instrument, and ergonomic advantages. Atallah et al. and others have reported on the feasibility of both robotic transanal excision of early rectal neoplasms and transanal TME for more advanced neoplasia [126–129].

Cost

The cost of purchase and maintenance of the robotic system has limited widespread application in many countries. Numerous reports show higher costs for the robot compared to laparoscopy but there are some exceptions [62]. Rawlings et al. showed no statistically significant difference in laparoscopic and robotic total hospital costs for right and sigmoid colectomies. Operating room supply costs were higher for the robotic right and sigmoid colectomies and operating room time costs were higher for robotic right colectomies, but not for sigmoid colectomies [29].

To date, most comparative cost analyses of minimally invasive surgery examine operative time, operating room supplies, pharmacy and anesthesia costs, and boarding costs. For the cost of the robotic approach to be comparable with respect to laparoscopic surgery, cost savings will have to be incurred by either decreasing hospital LOS, decreasing conversions, or decreasing another parameter of cost effectiveness. More recent comparative studies have shown hospital LOS and conversion rates more favorable for the robotic approach when compared to laparoscopy [37]. This includes recent analyses of large protocol-driven, externally audited, nonadministrative regional and national databases [89, 90].

Another consideration is the willingness to absorb the cost of an approach that may be applicable to a larger number of patients, particularly for rectal cancer. It is not clear yet what cost savings would be incurred for those patients who would otherwise require open surgery because laparoscopic TME is not part of their surgeon's skill set or who are converted from laparoscopic to open. Limiting the use of the robot to specialized centers may be another way of addressing cost, but this would exclude a significant number of patients from access to a minimally invasive approach. The penetration of laparoscopy in practice varies by region and many areas of the United States are underserved and have no minimally invasive options and are without access to surgeons with laparoscopic skill sets [108, 130]. Future cost analyses will likely include the cost of conversion to open, hospital LOS, Emergency Department visits, readmissions, return to health without symptoms, and other measures of cost effectiveness [16].

Future Directions

The quality of trials evaluating minimally invasive approaches continues to advance. Single site case series and comparative studies were followed by large database analyses. Recent analyses of large regional and national databases have shown advantages for robotic compared to laparoscopic colectomy with respect to conversion and hospital LOS [89, 90]. The strength of these database analyses is the source of the data. Regional databases like the Michigan Surgical Quality Collaborative are protocol driven and characterized by data that is entered by highly trained individuals, regularly validated, and externally audited. These database outcomes represent surgeons of varying minimally invasive skill sets and are therefore generalizable. They are potentially more valid with respect to outcomes when compared to databases that rely on administrative and billing information. Randomized controlled trials comparing robotic and laparoscopic approaches followed these database analyses, and the ROLARR trial which represents surgeons with significant minimally invasive expertise is complete [16]. These studies will likely lead to data that allows surgeons to choose minimally invasive options based on patient characteristics and their skill sets. These trials may also focus questions that require further study.

The Association for Program Directors in Colon and Rectal Surgery identified the issues of fellowship training in the laparoscopic era, especially with regard to the low penetrance of laparoscopic colorectal surgery among young fellowship-trained Colon and Rectal Surgeons [10]. In response, this organization has sponsored the development of a standardized national robotic training curriculum to address the challenges in fellowship training and to become proactive in training the Colon and Rectal Surgeons of the future. Ninety-five percent of the Colon and Rectal Surgery Fellows attended the standardized colorectal surgery robotic courses based on this curriculum in 2014. These efforts uncovered a need to train robotic mentors necessary to allow operative robotic educational opportunities for residents and fellows.

Future innovations in robotic technology may include telementoring surgeons at remote locations who may benefit from expert advice, telepresence surgery with the expert performing the robotic operation from a remote location, CT or MRI-guided robotic interventions, and other robotic-guided clinical applications [115, 131–133].

Until recently, a disadvantage to robotic colorectal surgery has been the need to operate in multiple quadrants, sometimes requiring redocking and negotiating external robotic arm collisions. The most recent upgrades in robotic technology address the issues of multiple docking and transanal access. What is possible with robotic technology is limited only by the imagination. Upgrades in minimally invasive platforms will likely result in options not yet evaluated or even considered. Today's robot is not yesterday's robot, and it is likely that future minimally invasive upgrades will allow current procedures to be done more effectively, and allow additional procedures not yet performed by a minimally invasive approach.

Conclusion

Robotic colorectal surgery was originally designed to reduce the laparoscopic limitations of decreased range of motion, instrument tremor, lack of instrument articulation, decreased depth perception, and ergonomic patient bedside disadvantages [62]. That the laparoscopic approach is utilized in only 45 % of elective colectomies and 10 % of elective TME in the United States is a testament to the degree of difficulty imposed by this minimally invasive option.

Studies to date comparing robotic with open and laparoscopic colorectal surgery suggest that the technical upgrades that improve imaging, instrument angles to tissues, surgeon-controlled stable camera and 3rd arm for fixed retraction, and robotic ergonomic appeal offer advantages, especially in the pelvis. This robotic advantage for rectal cancer appears to be most consistent with respect to conversion rates, hospital LOS, and may potentially affect circumferential margins and oncologic outcomes. A larger number of patients with rectal cancer now have the opportunity for minimally invasive surgery because of these robotic advantages in the pelvis.

Trials evaluating the role of the robotic approach for colectomy have also identified advantages to the robotic platform in this location, especially with regard to suturing the intracorporeal anastomosis, incisional hernias, and single-incision procedures. Upgrades in technology that have resulted in sleeker, more sophisticated robotic arms and single-incision ports will ultimately require further study. It is possible that the continued evolution of minimally invasive robotic upgrades will change the paradigm of minimally invasive colorectal surgery.

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Chapter 16
Robotic Costs

Deborah S. Keller and Eric M. Haas

Section 1: Introduction of Robotic-assisted Laparoscopic Surgery

Background

Colorectal surgery has historically embraced technology to improve efficiency and patient care. The introduction of laparoscopic colorectal surgery was a revolutionary technological advance for improving postoperative recovery, patient outcomes, and reducing overall healthcare costs compared to the open colorectal surgery [1–9]. Despite the proven benefits, recent studies show minimally invasive techniques are used in less than 50 % of total cases, less than 20 % for colon cancer, and less than 10 % for rectal cancer [10–12]. Robotic-assisted laparoscopic surgery (RALS) is a minimally invasive tool technology that could help expand the use of minimally invasive colorectal surgery, especially in the rectal diseases.

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Introduction of Robotic-assisted Laparoscopic Surgery

In 2001, the first robotic colorectal surgery was performed in the United States using the Intuitive Surgical's Da Vinci robotic system [13]. Since then, the use of RALS has continued to grow, increasing from 0.8% in 2008 to over 4% in 2009 for all general surgical procedures [14, 15]. For colorectal surgery specifically, an estimated 2.8 % of 130,000 annual procedures were performed through a RALS approach [14]. Several studies have evaluated outcomes with this promising tool, demonstrating equivalent safety with similar clinical and oncologic outcomes to traditional laparoscopic colorectal surgery [15–36].

Benefits of Robotic-assisted Laparoscopic Surgery

While reported outcomes are similar, there are distinct technical advantages with RALS that may help overcome limitations encountered with laparoscopic surgery, especially when operating in the pelvis [28, 37, 38]. The robot platform has a stable three-dimensional view and instruments offering improved ergonomics and motion. The increased precision and accuracy from these instruments may facilitate more complex pelvic dissections over the conventional laparoscopic surgery [26, 38]. RALS also has proven clinical advantages, such as lower estimated blood loss and lower conversion rates to open surgery in both benign and malignant colorectal conditions [14, 19, 23, 25, 26, 29]. It has been suggested the greatest benefit of RALS is in low anterior resections for rectal cancer [16, 28]. In such cases, the RALS platform may provide better postoperative nerve function and oncologic advantages of a higher quality Total mesorectal excision (TME) and lower local recurrence rates [19, 27, 39]. Despite the potential advantages to the surgeon and patient, RALS is still not widely utilized, one reason for which is the cost.

The Cost Challenge of RALS

The higher cost of RALS has been a major challenge to justifying widespread adoption [31]. Numerous studies have shown significantly higher costs for RALS over laparoscopic colorectal resections with similar outcomes, including comparable length of stay, readmission, and complication rates [14, 16, 25, 28, 32–34, 40–42]. Eight studies comparing RALS to the laparoscopic colorectal resections all supported higher direct and total costs, with no clear superiority in the short- or long-term outcomes (Table 16.1). Across these studies, the average increase in costs was $2142. In addition to higher total costs, consistently longer operative times for RALS compared to laparoscopy have also been reported [33]. Systematic review and meta analyses have also shown comparable oncological accuracy, circumferential

Table 16.1 Comparative analysis of RALS versus laparoscopic colorectal costs

Study (year)	RALS vs. LAP	Procedure	Benefit of RALS?	Total cost (RALS)[≠]	Total cost (Lap)[≠]	Difference
Delaney (2003)	6 vs. 6	RH, SC, RP	No	$3721[a]	$2946[a]	$776[a]
Rawlings (2007)	15 vs. 17 12 vs. 13	RC SC	No	$9255 $12,335	$8037 $10,697	$1182 $1638
deSouza (2010)	30 vs. 92	RH	No	$15,192[a]	$12,361[a]	$2831[a]
Haas (2011)	32 vs. 32	AR, LAR	No	$16,708	$15,401	$1307
Park (2012)	35 vs. 35	RH	No	$12,235	$10,320	$1915
Bae (2012)	154 vs. 150	TME	No	$14,647	$9978	$4669
Koh (2014)	19 vs. 19	TME	No	$12,460	$8560	$3000

AR: anterior resection; *LAR*: low anterior resection; *RH*: right hemicolectomy; *RP*: rectopexy; *TME*: total mesorectal excision.

[a] Represents median cost

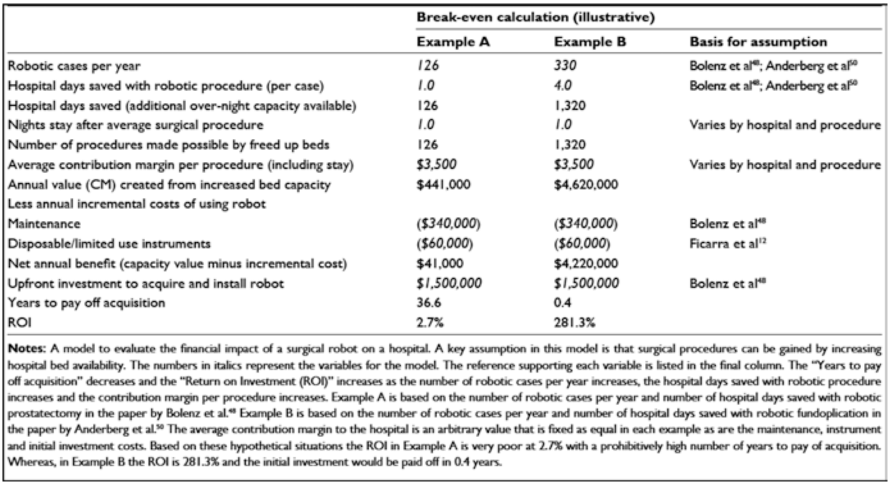
[≠] Represents total direct cost

resection margin involvement, distal resection margin, and lymph node yield compared to the laparoscopic proctectomy for rectal cancer [25, 29]. In a time of increasing pressure on healthcare utilization, it is necessary to ask if the increased costs are worthy for outcomes of lower intra-operative conversion and transfusion rates? And, do these perceived benefits warrant the investment to purchase and train on the robot?

Section 2: Changing the Paradigm

Defining the Optimal Model for RALS: Evaluating Success in Other Fields

Despite the current concerns regarding its cost, RALS continues to grow. Therefore, it is necessary to change the paradigm to make RALS cost-effective. The best clinical model for effective integration of RALS into practice is in urology. Recognizing a need, with the large amount of suturing required and the lack of progression to laparoscopy, there was wide and rapid adoption of robotic surgery in urology [43]. Robot-assisted radical prostatectomy increased from 1% in 2001 to more than 50% of all prostatectomies performed in the United States in 2009 and is currently recognized as the gold standard [44]. Even in this optimal model, robotics is associated with higher costs than open and laparoscopic prostatectomy, predominantly from higher surgical supply and



	Break-even calculation (illustrative)		
	Example A	Example B	Basis for assumption
Robotic cases per year	*126*	*330*	Bolenz et al[48]; Anderberg et al[50]
Hospital days saved with robotic procedure (per case)	*1.0*	*4.0*	Bolenz et al[48]; Anderberg et al[50]
Hospital days saved (additional over-night capacity available)	126	1,320	
Nights stay after average surgical procedure	*1.0*	*1.0*	Varies by hospital and procedure
Number of procedures made possible by freed up beds	126	1,320	
Average contribution margin per procedure (including stay)	*$3,500*	*$3,500*	Varies by hospital and procedure
Annual value (CM) created from increased bed capacity	$441,000	$4,620,000	
Less annual incremental costs of using robot			
Maintenance	*($340,000)*	*($340,000)*	Bolenz et al[48]
Disposable/limited use instruments	*($60,000)*	*($60,000)*	Ficarra et al[12]
Net annual benefit (capacity value minus incremental cost)	$41,000	$4,220,000	
Upfront investment to acquire and install robot	*$1,500,000*	*$1,500,000*	Bolenz et al[48]
Years to pay off acquisition	36.6	0.4	
ROI	2.7%	281.3%	

Notes: A model to evaluate the financial impact of a surgical robot on a hospital. A key assumption in this model is that surgical procedures can be gained by increasing hospital bed availability. The numbers in italics represent the variables for the model. The reference supporting each variable is listed in the final column. The "Years to pay off acquisition" decreases and the "Return on Investment (ROI)" increases as the number of robotic cases per year increases, the hospital days saved with robotic procedure increases and the contribution margin per procedure increases. Example A is based on the number of robotic cases per year and number of hospital days saved with robotic prostatectomy in the paper by Bolenz et al.[48] Example B is based on the number of robotic cases per year and number of hospital days saved with robotic fundoplication in the paper by Anderberg et al.[50] The average contribution margin to the hospital is an arbitrary value that is fixed as equal in each example as are the maintenance, instrument and initial investment costs. Based on these hypothetical situations the ROI in Example A is very poor at 2.7% with a prohibitively high number of years to pay of acquisition. Whereas, in Example B the ROI is 281.3% and the initial investment would be paid off in 0.4 years.

Fig. 16.1 Break-even analysis for robotic surgery. From Leddy LS, Lendvay TS, Satava RM. Robotic surgery: applications and cost-effectiveness. Open Access Surgery. 2010;3:99–107

OR cost due to increased operative time [45]. The value comes from reducing the length of stay, with cost savings realized when enough nights in the hospital are saved to overcome the increased cost of the robotic procedure [46]. The shorter length of stay and faster recovery when transitioning from open to robotic models has been proven in multiple studies [47–51]. Study has found the length of stay for RALS was 1 day shorter than laparoscopic and 2 days shorter than open prostatectomy [45]. When determining if there is a value in integrating RALS into clinical practice, a break-even analysis is beneficial. An example of the cost–benefit analysis for integration of RALS is shown in Fig. 16.1.

Targeting Open Surgery

Minimally invasive procedures are the most overall cost effective. Most reports on the cost concerns of RALS compare laparoscopic and robotic colorectal resections [14, 32, 41, 42]. However, these comparisons are short sighted. RALS is a minimally invasive tool; it is not intended to steal market share from laparoscopic surgery. Despite proven benefits of minimally invasive rectal cancer surgery, its use is still estimated at 10% nationwide; 90% of rectal cancer cases are still performed open [10]. The value of RALS is in converting *open* to robotic surgery and expanding the use of minimally invasive procedures in general. National studies on robotic trends further that benefits are most pronounced when robotics is used in procedures previously performed open [15, 52]. For all common general surgery procedures, length of stay was shorter, with fewer complications and lower or equivalent mortality in the RALS compared to open cases [52]. The trends of shorter length of stay with lower complication and mortality rates were also seen in RALS versus open surgery in colorectal procedures specifically [15]. Compared to open surgery, the improved functional outcomes, reduction in postoperative pain, faster time to recover normal bowel function, and shorter length of stay make the value proposition against the cost for purchasing and integrating RALS in colorectal surgery [53]. When overall costs were considered, RALS appears more cost-effective than open surgery for colorectal procedures [15]; this same value proposition was seen during the evolution from open to laparoscopic surgery. As RALS enables open surgeons to perform more minimally invasive procedures, it can follow the model of urology, reaching overall cost reductions in length of stay and faster recovery.

Creating a Market Niche

Recognizing laparoscopic surgery for rectal cancer continues to be associated with low national adaption rates, RALS may be positioned as tool for increasing minimally invasive rectal cancer resections [10, 28, 41, 54]. RALS has definite advantages over open TME for rectal cancer, including significantly more lymph nodes harvested, less estimated blood loss, a shorter length of stay, faster postoperative recovery, and a significantly lower local recurrence rate [39, 55]. The robot system may overcome challenges associated with difficult pelvic anatomy, which could increase the percent of patients that undergo a minimally invasive resection [38]. The RALS approach even has benefits over laparoscopy for TME including lower conversion rates, better quality of the TME specimen, and faster recovery of urinary and sexual function, increasing the value proposition [27, 56–58]. Several characteristics have been defined as selection criteria for robotic surgery to justify its increased cost, including obesity, male sex, preoperative radiotherapy, and tumors in the lower two-thirds of the rectum [59]; rectal cancer patients with these characteristics should be considered prime candidates for RALS. RALS may be the means to increase MIS for rectal procedures. Using the platform to allow a skilled laparoscopic surgeon to overcome the barriers of pelvic surgery and offer a minimally invasive approach to rectal cancer patients is a true benefit of RALS. RALS could feasibly transition a 10% increase in utilization of minimally invasive surgery for rectal cancer cases. At 20%, the paradigm shift from open to minimally invasive surgery occurs, and true economic benefits are realized.

Streamlining Instrumentation

As we work to change the paradigm from open to robotic colorectal surgery, there are methods to streamline costs now. Standardizing and reducing instrumentation is a way to reduce the unnecessary costs. The Da Vinci surgical system has no third-party disposables available, offering an ability to standardize equipment that laparoscopic surgery could never offer. For example, the proprietary EndoWrist 45 (Intuitive Surgical, Inc.) robotic stapler may be more cost-effective than a separate

Non-standardized equipment table | Standardized equipment table

Fig. 16.2 Standardized versus non-standardized equipment table

Table 16.2 Example of a standardized equipment pack for robotic-assisted laparoscopic surgery

1 BLADE SURG SS 15	3 GOWN SURGICAL XL
1 CHLORAPREP 25ML ORANGE	1 COVER MAYO STAND 23X54IN REINF
1 TUBING SUCTION 1/4X144IN	1 BOWL GRADUATED 32Z
2 SYRINGES 10ML L/L	1 BAG SUT BLU FL
1 DRAPE LAP W/PCH 11X72X124IN	10 GAUZE 4X4 16PLY XR
2 DRAPE LAP 60X76IN	5 SPONGE LAP 18X18
12 TOWEL OR BLUE	2 COVER LT HNDL RIGID
1 CAUTERY BUTTN W PENCIL W EZ CLN	1 YANKAUER SUCTION TIP W/O VENT
1 CORD MONOPOLAR	1 SYRINGE BULB BLUE 60CC
1 NDL CNTR MEG/ FM 10CT	1 SKIN MARKER RND DUAL TIP
1 NDL NEG BVL 25GA 1.5IN	1 COVER TABLE 44X88FF
1 NDL NEG BVL 18GA 1.5IN	1 CVR BK TBL 60X90IN ZONE REINF

laparoscopic instrument. Holzmacher et al. retrospectively compared the EndoWrist 45 to laparoscopic staplers in patients who underwent RALS colorectal procedures [60]. The laparoscopic stapler group required significantly more fires per patient than the robotic stapler group (2.69 vs. 1.86; $p=0.001$) and had significantly higher stapler cost per patient ($631.45 vs. $473.28; $p=0.001$), demonstrating the cost-effectiveness of the robotic accessory [60]. Delto et al. demonstrated the impact of streamlining equipment to optimize the cost–benefit of robotic technology without negatively impacting operative time, blood loss, or intra-operative complications [47]. By eliminating a laparoscopic energy source in lieu of inexpensive tools (such as Hem-o-lock clips), instrumentation costs were reduced by approximately 40% [47]. Each robotic case across all service lines uses the same basic instruments, so a standardized peel pack and instrument table can reduce unnecessary equipment costs. An example of a standardized and non-standardized equipment table, and the contents of a standardized peel pack for RALS are seen in Fig. 16.2 and Table 16.2. The robotic instruments are also highly multi-functional and can be exploited to perform more tasks and contain costs. For example, using the hook instead of monopolar shears will save $120 per procedure. At a hospital that performs 100 colorectal procedures annually, this change on just 50% of the procedures will save $6000. Utilizing the suturing capabilities of the robot instead of a laparoscopic tacker in cases that use mesh fixation, such as a rectopexy, will save $500–700 per procedure. Depending on the volume of the institution, streamlining and maximizing the capabilities of the robotic instruments can result in significant cost savings.

Increasing Case Volume

The cost of each RALS case is determined by robotic system value/ the number of cases performed. Therefore, increasing the number of cases is a method to reduce the cost per case and make the tool more cost-effective. A recent review of the Premier Persepectives® database found only 13% of hospitals and 4.4% of surgeons performed a high volume of robotic colorectal cases [61]. The majority of colorectal RALS were performed by low volume surgeons (less than or equal to five cases) at low volume hospitals (less than or equal to ten cases). Furthermore, low volume providers were associated with significantly more overall complications, longer length of stay, and higher costs at both the hospital and surgeon level [61]. In addition, increasing use of robotics in other service lines will increase the total case numbers and ability to profit through economies of scale. A study has shown the technology can become cost-effective in high-volume centers with high-volume surgeons [62]. Thus, increasing individual case volumes and/or regionalizing RALS cases to a high volume center could reduce the individual cost per procedure and increase the overall revenue.

Instituting Quality Control Metrics

Facility costs can be impacted by shorter console/operative times. The attenuated learning curve with RALS has already been discussed. Another way to reduce the operative times and realize cost savings is to institute quality control measures around docking time. Docking times have been reported as a median of 10 min, but with a wide variation (range: 2–70 minutes) [63]. Docking should be a 3–5 min drill regardless of the case. Establishing docking time as a best practice, and tracking docking times against the benchmark has the potential to dramatically reduce costs. For example, if docking currently takes 15 min, at an average cost of $60 per operating room minute, in a practice that performs 2 RALS cases per operating day, and operates 100 days a year, the cost is: 15 min × ($60/min) × 2 cases/operative day × 100 operative days = 180,000. By reducing the docking time to an average of 3 minutes, the costs are reduced to $36,000, for a cost savings of $144,000.

Marketplace Competition

To reduce the capital cost, advances in robotic technology and competition in the marketplace to reduce the cost of the surgical robotic and its equipment are needed. Although costs are currently high, increased competition from

Table 16.3 Definitions of the cost model

Total cost (TC): Sum of direct cost and indirect cost (TC = DC + IC)
Direct cost (*DC*): Sum of variable cost and fixed direct cost (DC = VC + FDC)
Variable (*supply*) *cost* (*VC*): Charges incurred for supplies during hospital course (labs, medications, robotic instruments, surgical drapes, blood transfusions, etc.)
Fixed direct cost (*FDC*): Unvaried charges associated with depreciation of surgical equipment and payment of indirect treatment-related personnel salaries/benefits (operating room supervisor, nursing managers, etc.)
Indirect cost (*IC*): Overhead, expenses of operating the hospital (hospital administration salaries/benefits, utilities, etc.)
Charges (*Ch*): Gross billing for costs incurred from surgical procedure and hospital course
Net revenue (*NR*): Received payment based on applicable payer contracts with institution
Contribution margin (*CM*): Difference between net revenue and direct cost (CM = NR − DC); allocated to pay indirect cost (associated non-treatment-related expenses)

manufacturers and wider dissemination of the technology could drive down the costs [64]. Intuitive Surgical's robotic system currently dominates the market, but Titan Medical (Toronto, Ontario) has an alternative, the Single Port Orifice Robotic Technology (SPORT™) Surgical System, in clinical trials.

Putting It All Together to Maximize Profitability

In sum, understanding the cost model is paramount to making RALS a cost-efficient tool in every institution. The key to a profitable program is the contribution margin. The contribution margin is defined as the net revenue minus the direct costs (Table 16.3). To increase the contribution margin, RALS can increase reimbursement by improving the payor mix and the related reimbursement. RALS may have higher costs, but there is the ability to improve other variables in the cost model to make RALS more cost-effective. Variables to factor into the cost model include:

- Fixed capital costs (cost of the amortized equipment)
- Maintenance costs
- Consumables
- Facility costs

Fixed capital and maintenance costs can be addressed with advances in robotic technology and increased competition. Streamlining instrumentation can optimize the cost of consumables. Reducing operative and docking times to increase the number of total cases performed can reduce the facility costs. In addition, increasing use of robotics in other service lines will increase the total case numbers and ability to profit through economies of scale.

Section 3: RALS Versus Laparoscopic Surgery: An Institutional Study of Patients and Financial Outcomes

To evaluate the cost-effectiveness of robotics at our institution, we performed a case-matched review of RALS versus laparoscopic low anterior and anterior resections. Patients were matched on body mass index (BMI), surgeon, indication for operation, and procedure performed. Clinical and financial outcomes were analyzed. The main outcome measures were the conversion rates, length of stay, complications, charges, revenue, total costs, and contribution margin in each cohort. During the study period, 32 RALS and 32 laparoscopic patients were evaluated. The patients were well matched in all demographics (Table 16.4). The RALS group had significantly longer operative times than the laparoscopic group ($p < 0.001$), but they had equivalent conversion rates. The length of stay, complications, and readmission rates were comparable (Table 16.5). The total cost and charges were higher in the RALS cohort, but the net revenue and

Table 16.4 Patient demographics

Parameters	RALS ($n = 32$)	LAP ($n = 32$)	p-value
Gender	9 females (28.1%)/23 males (71.9%)	13 females (40.6%)/19 males (59.4%)	0.30
Age (years)	53.9 ± 11.7 (range: 30–82)	59.1 ± 13.0 (range: 32–88)	0.10
BMI (kg/m^2)[a]	28.9 ± 6.0 (range: 16.0–46.9)	28.4 ± 5.9 (range: 18.5–48.8)	0.75
ASA	2.5 ± 0.5 (range: 2–3)	2.4 ± 0.5 (range: 2–3)	0.62
Pathology[a,b,c]	24 benign (75 %)/8 malignant (25 %)	24 benign (75 %)/8 malignant (25 %)	1.0
Procedure[a]	25 AR (78.1 %)/7 LAR (21.9 %)	25 AR (78.1 %)/7 LAR (21.9 %)	1.0

[a] Matching criteria (surgeon and hospital were also matched)
[b] Benign pathology included recurrent and complicated diverticulitis
[c] All malignant cases were adenocarcinoma of the rectum and rectosigmoid

Table 16.5 Clinical outcome data

Parameters	RALS ($n = 32$)	LAP ($n = 32$)	p-value
OT (min)	230.9 ± 51.4 (range: 135–330)	166.2 ± 48.3 (range: 75–279)	<0.001[*]
EBL (mL)	96.9 ± 46.6 (range: 25–200)	108.1 ± 79.6 (range: 25–300)	0.49
Conversion	0(0.0 %)	0(0.0 %)	1.0
LNE[a]	17.0 ± 4.5 (range: 10–23)	17.4 ± 4.2 (range: 12–23)	0.99
LOS (days)	3.9 ± 2.9 (range: 2–14)	3.6 ± 2.0 (range: 2–12)	0.58
Complications[b]	9 (28.1 %)	7 (21.9 %)	0.57
Readmission[b]	4 (12.5 %)	3 (9.4 %)	0.69

[a] For malignant cases only
[b] During 30-day follow-up
[*] Statistical significance

Table 16.6 Financial outcome data

Parameters	RALS ($n = 32$)	LAP ($n = 32$)	Mean difference (RALS – LAP)	p-value
Charges	\$50,839.59 ± 16,882.75	\$43,824.12 ± 17,389.30	\$7015.47	0.11
Total cost	\$16,708.40 ± 4592.21	\$15,401.69 ± 4744.07	\$1306.71	0.27
Net revenue	\$17,660.27 ± 12,600.13	\$13, 546.75 ± 7499.64	\$4113.52	0.12
Contribution margin	\$8702.51 ± 11,708.48	\$5360.91 ± 5534.32	\$3341.60	0.15

contribution margin were also higher in RALS than the laparoscopic group. While not statistically significant, the values were economically different, with a profit of \$3,341 per patient and \$106,973 for the series (Table 16.6). Even with a higher total cost, RALS can be profitable in colorectal surgery when evaluating the entire cost model.

Conclusions

Robotic-assisted laparoscopic surgery is an evolving tool that can further the capabilities and outcomes of traditional laparoscopic surgery. Widespread utilization has been limited by higher total costs of RALS. Changing the paradigm to focus on transitioning open procedures to RALS and using simple methods to optimize profitability can make RALS a cost-effective and efficient minimally invasive tool.

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Chapter 17
The Robotic-Assisted Treatment of Endometriosis: A Colorectal Surgical Perspective

Maria Victoria Vargas, Gaby Moawad, Vincent Obias, and Madiha Aziz

Background

Endometriosis is a common benign gynecologic condition defined as the presence of uterine lining, or endometrium, outside of the uterine cavity. Specifically, pathologic diagnosis is based on the presence of ectopic endometrial glands and stroma [1]. Implants of endometriosis are hormone responsive, expressing both estrogen and progesterone receptors. A proinflammatory environment is present secondary to the production of cytokines, prostaglandins, and metalloproteinases. The inflammation present in endometriosis lesions leads to scar tissue formation and adhesions between pelvic organs. In addition, endometriotic implants release angiogenic and neurogenic growth factors leading to the expression of nerve fibers, lymphatic vessels, and blood vessels in the tissue surrounding the implants as well as the implants themselves [2]. The most common anatomical locations affected by endometriosis are the pelvic peritoneum and the ovaries, but endometriosis can involve almost any organ including the pericardium, pleura, and the brain [3]. Common symptoms of endometriosis include painful menses, chronic pelvic pain, pain with intercourse, and infertility. Symptoms also vary by anatomic involvement, such as significant dysuria with bladder involvement, flank pain with ureteric involvement, and dyschezia with bowel involvement [4].

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Pathophysiology

The exact etiology of endometriosis is unknown, but a number of hypotheses have been described. The most well accepted is the transplantation theory, which suggests that retrograde menstruation through the fallopian tubes allows for the implantation of ectopic endometrial glands on the pelvic peritoneum [5]. This hypothesis is supported by the increased incidence of endometriosis in women and girls with Müllerian anomalies that lead to obstruction of menstrual outflow through the vagina [6]. In addition, it is suggested that the cause of endometriosis of surgical incisions, such as in episiotomy and cesarean section incisions, is similarly caused by transplantation of endometrial tissue during delivery or surgery [7]. The second hypothesis is that of lymphatic or hematogenous spread [8], which is supported by reports of endometriosis in distant sites, such as the lungs [9] and the brain [10]. The third theory is that of coelomic metaplasia. This theory proposes that undifferentiated mesothelial cells of the coelomic (peritoneal) cavity have the potential to differentiate into endometrial cells. This hypothesis is supported by embryologic studies suggesting that all pelvic organs, including the endometrium, originate from cells lining the coelomic cavity [11]. In addition to these three theories, studies suggest that exposure to toxins, altered immunity, and genetic predisposition influence susceptibility to endometriosis [12].

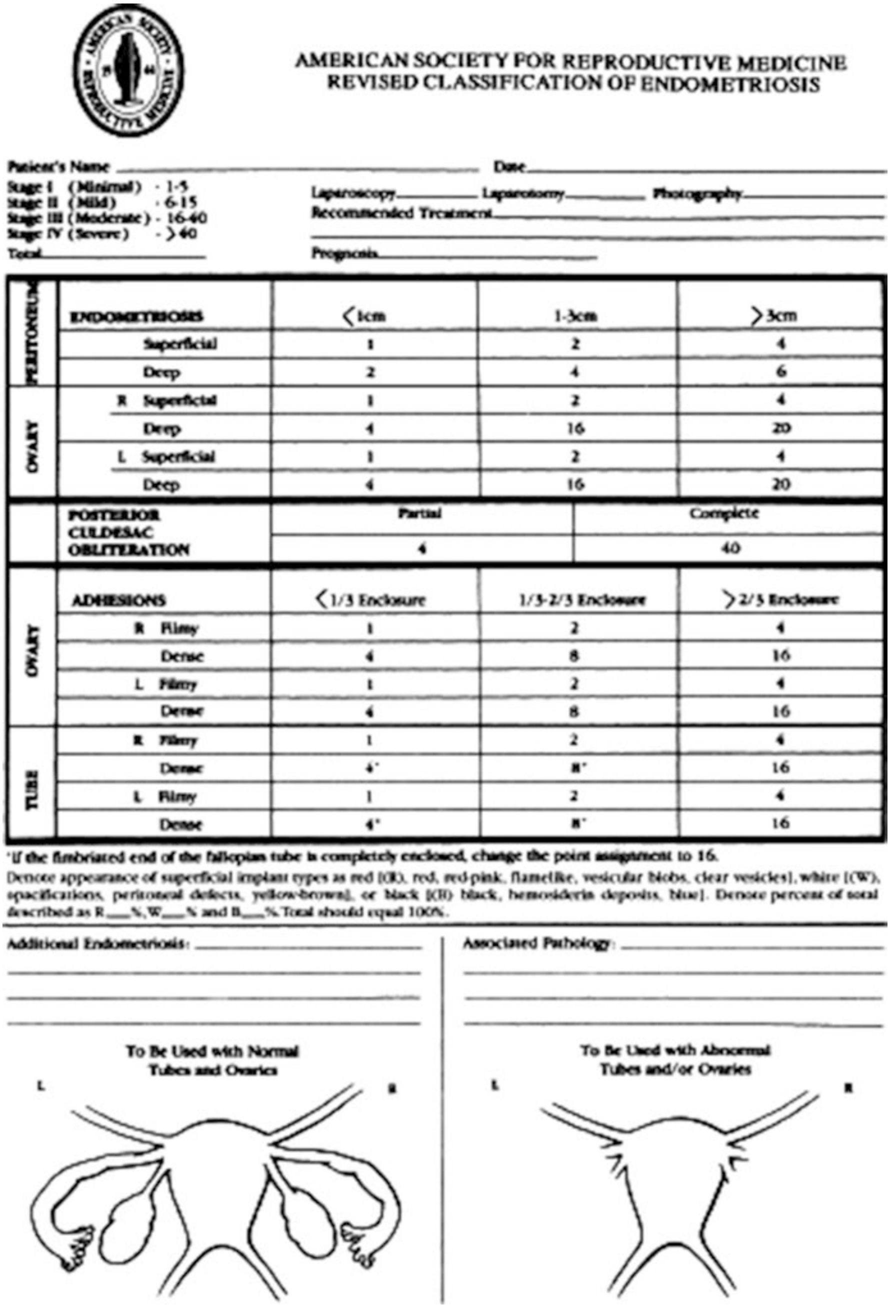
Epidemiology

Though endometriosis is estimated to affect 6–11 % of reproductive age women, up to a third of women do not have symptoms of the disease [13]. In subgroups of women manifesting symptoms of endometriosis, prevalence rates are markedly increased. For example, women with chronic pelvic pain have an estimated prevalence of 25 % [14], and women with infertility have an estimated prevalence of 25–40 % [15].

Disease Classification

Upon surgical exploration, endometriosis can present in a spectrum from mild disease involving only superficial peritoneum of the pelvis, to severe disease causing dense adhesions that fix pelvic structures completely.

Disease severity has been historically described using the American Society of Reproductive Medicine (ASRM) endometriosis staging system (Fig. 17.1), which was originally designed in 1979 and was most recently revised in 1997 [16]. The ASRM endometriosis staging system considers factors such as lesion appearance, size, depth of invasion, and location. Depending on these factors, points are assigned and endometriosis is classified as stage I (mild), stage II (minimal), stage III (moderate), and stage IV (severe).



AMERICAN SOCIETY FOR REPRODUCTIVE MEDICINE
REVISED CLASSIFICATION OF ENDOMETRIOSIS

Patient's Name ______________ Date ______________

Stage I (Minimal) - 1-5
Stage II (Mild) - 6-15
Stage III (Moderate) - 16-40
Stage IV (Severe) - >40
Total ______________

Laparoscopy ________ Laparotomy ________ Photography ________
Recommended Treatment ______________
Prognosis ______________

	ENDOMETRIOSIS	<1cm	1-3cm	>3cm
PERITONEUM	Superficial	1	2	4
	Deep	2	4	6
OVARY	R Superficial	1	2	4
	Deep	4	16	20
	L Superficial	1	2	4
	Deep	4	16	20

		Partial	Complete
	POSTERIOR CULDESAC OBLITERATION	4	40

	ADHESIONS	<1/3 Enclosure	1/3-2/3 Enclosure	>2/3 Enclosure
OVARY	R Filmy	1	2	4
	Dense	4	8	16
	L Filmy	1	2	4
	Dense	4	8	16
TUBE	R Filmy	1	2	4
	Dense	4*	8*	16
	L Filmy	1	2	4
	Dense	4*	8*	16

*If the fimbriated end of the fallopian tube is completely enclosed, change the point assignment to 16.

Denote appearance of superficial implant types as red [(R), red, red-pink, flamelike, vesicular blobs, clear vesicles], white [(W), opacifications, peritoneal defects, yellow-brown], or black [(B) black, hemosiderin deposits, blue]. Denote percent of total described as R___%, W___% and B___%. Total should equal 100%.

Additional Endometriosis: ______________

Associated Pathology: ______________

To Be Used with Normal Tubes and Ovaries

To Be Used with Abnormal Tubes and/or Ovaries

Fig. 17.1 Revised American Society for Reproductive Medicine classification of endometriosis

Several limitations exist with this system including lack of reproducibility [17] and poor correlation of symptoms with stage of disease [18, 19]. In 2005, the ENZIAN [20] system was proposed as an adjunct to the ASRM staging of endometriosis to describe deeply infiltrative disease in further detail. More recently, the Endometriosis Fertility Index (EFI) was developed and validated for the prediction of spontaneous pregnancy in women with endometriosis [21, 22]. This system considers patient characteristics such as age, duration of infertility, ASRM score, and the extent of disease involving the ovaries and fallopian tubes. Though both the ENZIAN and EFI systems have recognized clinical utility, neither has been widely adopted for the staging of endometriosis.

From a clinical standpoint, endometriosis is distinguished by three distinct manifestations: (1) superficial endometriosis, (2) ovarian endometriomas, and (3) deeply infiltrating endometriosis (DIE) [23, 24]. Though they can present simultaneously, these three types of endometriosis vary in severity, symptoms, and management.

DIE is of the most clinical importance from a colorectal surgical perspective. This is the most advanced form of endometriosis and is relatively rare, estimated to affect 1–3 % of all reproductive age women [25]. These lesions invade beyond the superficial peritoneum and can involve sites such as the rectovaginal space, the bowel, appendix, bladder, ureter, lung, liver, umbilicus, as well as other locations (Fig. 17.2). When DIE involves the rectosigmoid, such as with transmural

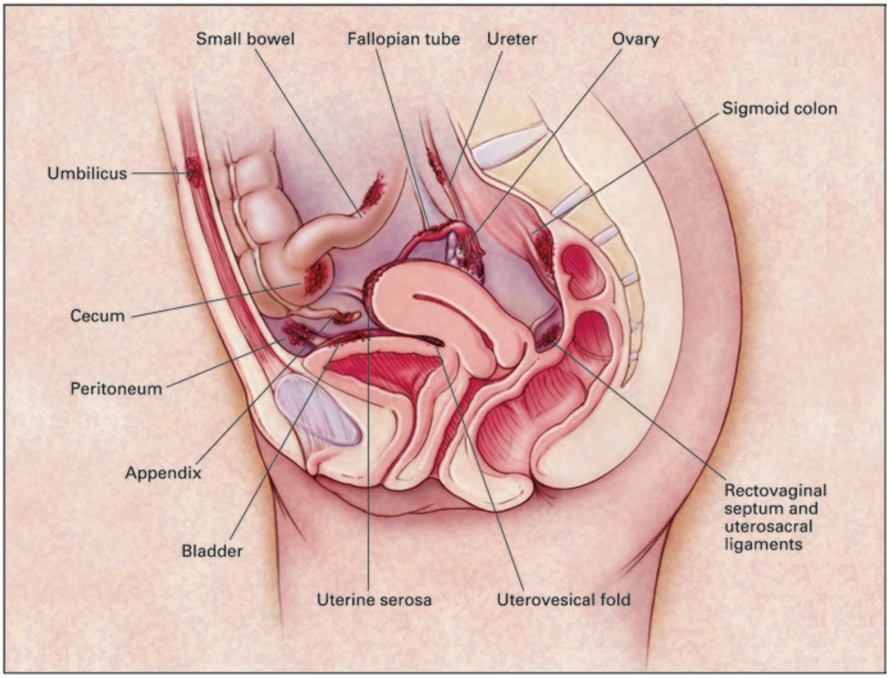


Fig. 17.2 Common locations of endometriotic lesions

infiltration leading to stenosis or obstruction, a preoperative colorectal surgical consultation and multidisciplinary surgical approach are often necessary.

Symptoms

Symptoms of endometriosis can be debilitating, affecting work productivity and quality of life [26]. Severe dysmenorrhea and chronic pelvic pain are the most common symptoms of women diagnosed with endometriosis. In a study of 1000 women with endometriosis, 79 % reported having dysmenorrhea and 69 % reported chronic pelvic pain [27]. Dyspareunia, another common symptom, is reported in 45 % of women with endometriosis [27] and is associated with rectovaginal and uterosacral involvement [28]. Dysuria, dyschezia, constipation, and diarrhea [29] may also be present and can be suggestive of DIE involving the bladder and bowel, respectively. However, these symptoms may also be present without deeply infiltrative disease [25, 26]. In cases of DIE of the rectosigmoid, cyclic hematochezia may be reported [30], and in rare cases of transmural infiltration of lesions, stenosis and even occlusion of the intestinal lumen can occur [31, 32].

Another common manifestation of endometriosis is infertility. Up to 50 % of women with endometriosis suffer from infertility and even higher rates can be seen with worsened disease severity. In some cases, infertility is the only symptom suggesting the presence of endometriosis [15].

Other symptoms seen with endometriosis include myofascial pain syndromes, painful bladder syndrome, irritable bowel type symptoms, depression, and anxiety.

Diagnosis

Historically, the formal diagnosis of endometriosis involving the abdominal cavity has been through laparoscopy, with or without biopsy for histologic evaluation [3]. However, the presence of endometriosis can be suggested clinically with the assistance of a good history, exam, and appropriate imaging. Thus, it is commonly suggested that surgery should be reserved for therapeutic purposes rather than diagnosis.

A history suggestive of endometriosis would include the symptoms discussed earlier (i.e., a long history of disabling dysmenorrhea, chronic pelvic pain, dyspareunia, infertility, irritable bowel type symptoms, fatigue, depression, and anxiety). Depending on the severity of disease, the physical examination may vary. In the case of superficial endometriosis, lesions cannot be palpated on bimanual exam. Endometriomas may be palpable on bimanual or abdominal examination depending on the size. Adnexal tenderness may also be present. Deeply infiltrating nodules of endometriosis are often palpable on bimanual and rectovaginal examination as uterosacral nodularity, retroflexion of the uterus, and fixation of the posterior cul-de-sac. When concomitant myofascial or painful bladder syndrome symptoms are present, levator ani pain and bladder pain may also be present.

Transvaginal ultrasonography is the initial imaging study of choice and when possible, should be performed in the late secretory phase of the menstrual cycle given that this is when the disease is most active. Superficial lesions are often not visible on transvaginal ultrasonography but endometriomas can be reliably diagnosed with this imaging modality [33]. For cases of DIE, transvaginal and transrectal ultrasonography can be useful for the identification of lesions involving the rectovaginal septum, parametrium, and uterosacral ligaments [34]. However, ultrasonography is highly operator dependent and it can lack sensitivity for smaller nodules of DIE [33]. In addition, many facilities lack the option to provide transrectal sonographic imaging.

T1- and T2-weighted magnetic resonance imaging (MRI) with and without fat suppression can reliably diagnose small nodules when DIE is suspected but transvaginal ultrasound is equivocal. MRI should be performed with and without gadolinium. When bladder involvement is suspected, ensuring a full bladder during MRI may enhance the ability to recognize nodules. When rectal involvement is suspected, a bowel prep followed by an antispasmodic agent to reduce artifact from peristalsis may also enhance the sensitivity of MRI [35].

In cases where bladder and/or ureteric endometriosis are suspected, renal ultrasonography and intravenous urography can assist with diagnosis. In addition, rectosigmoidoscopy should be performed, ideally during menses, if rectal infiltration is suspected [12].

Treatment of Endometriosis

Medical Therapy

Treatment algorithms are dependent on patient symptomatology, location of lesions, and desire to conserve the option for future childbearing. In patients presenting with mild to moderate pain and without the desire for immediate conception, empiric medical therapy is appropriate. First-line regimens include combined oral contraceptives (COCs) and progestins. There is abundant observational data to support the use of combined oral contraceptives (COCs) for the relief of endometriosis-related pain. COCs act to cause an inactivation of implants through a process of decidualization [36]. Regimens for oral contraceptives may be cyclic but extended cycle and continuous regimens are often used for women with disabling dysmenorrhea. COCs have a good side effect profile and are generally well tolerated by patients. For women on extended cycle and continuous regimens, break through bleeding is the most common side effect [37]. For women who are not candidates for estrogen containing therapy, progestins alone are utilized. These agents inactivate endometrial implants by antagonizing the effects of estrogen. One randomized trial examined the effectiveness of medroxyprogesterone acetate against placebo to cause regression of endometriotic implants. Women who received medroxyprogesterone acetate had significant reduction of lesions after 6 months on second-look laparoscopy when compared to women who received placebo. Symptoms were improved in the medroxyprogesterone actetate group as well [38]. Other progestins have also been shown to improve symptoms related to endometriosis, such as norethindrone acetate and the levonorgestrel intrauterine device [39, 40]. Side effects of progestins can include weight gain, edema, acne, and irregular bleeding which may limit their acceptability by patients.

For women with symptoms refractory to COCs and progestins, second-line agents include gonadotropin releasing hormone (GNRH) agonists, such as leuprolide acetate. There is strong evidence supporting the efficacy of GNRH agonists to reduce pain related to endometriosis. However, GNRH agonists also lead to a hypoestrogenic state simulating menopause and side effects can be poorly tolerated. These include significant loss of bone mineral density and vasomotor symptoms (hot flashes) [41]. Combining GNRH agonists with low dose "add-back" hormone therapy significantly reduces the hypoestrogenic effects and makes the regimen more tolerable for patients. Aromatase inhibitors have been more recently introduced as a potential treatment for endometriosis-related pain. Several studies have shown that these agents reduce pain symptoms in women with endometriosis. When used alone, they share a similar side effect profile to GNRH agonists that make them difficult to tolerate. However, recent study of aromatase inhibitors with combined oral contraceptives showed significant pain relief with an improved acceptability. This option remains promising for otherwise refractory cases but is not yet widely utilized. Androgens, such as danazol, have also been shown to significantly reduce the size of endometriotic lesions and improve pain symptoms, but have significant androgenic effects making them generally not well accepted by patients [2].

Surgical Therapy

When symptoms are refractory to medical therapy, or in circumstances that preclude the use of medical treatments, surgery is the next approach to treatment. For superficial disease, studies comparing surgical treatment through excision or ablation of endometriotic lesions show a significant improvement in pain (63 % versus 23 %) when compared to expectant management. Studies comparing ablative techniques, such as laser ablation versus electrosurgical ablation, have not found a difference in symptom relief [42]. In addition, studies assessing excisional removal versus ablative removal of superficial endometriotic lesions did not show a significant difference in symptoms [42].

In the case of endometrioma, moderate level data supports excisional surgery for the relief of pain symptoms. Women with small endometriomas that are asymptomatic present a challenge, as there is little data to suggest that excisional therapy has benefits over medical management [43].

For the management of deeply infiltrative endometriosis associated with moderate to severe pain, excisional surgery is the current standard of care. However, surgery for DIE is technically challenging and up to 35 % of women need a bowel resection as part of their management [44]. Thus, surgical expertise and a multidisciplinary approach involving colorectal surgery are necessary to safely complete this type of surgery.

A number of studies have demonstrated relief of pain with excisional surgical treatment for DIE. In 2014, Fritzer and colleagues performed a systematic review of three studies that included a total of 128 patients. The authors assessed surgical intervention for the management of refractory pain in women with deeply infiltrative endometriosis. Significant reductions in overall pain and sexual function were seen [45]. The authors noted that though pain was improved and complications were rare, the surgeries required were often radical, thus putting patients at risk for related complications. The most commonly reported complications were hemorrhage requiring transfusion and formation of rectovaginal fistula. A prospective cohort study of 83 patients with rectovaginal endometriosis evaluated long-term outcomes after radical excisional surgery. Though the majority of patients had improvement in symptoms, about 40 % of these patients required bowel resection. In addition, the study showed a 30 % rate of recurrence over time [46]. Complications included bladder denervation with associated atony, and hemorrhage requiring transfusion.

With regards to surgical treatment of endometriosis for infertility, well-designed trials are lacking. A randomized control trial comparing diagnostic laparoscopy with excisional or ablative removal of mild endometriosis showed a statistically significant, but clinically modest, improvement in cumulative pregnancy rates in women with surgical removal. A subsequent smaller trial showed no difference in pregnancy rates in women who had a diagnostic surgery versus a therapeutic surgery [47]. In women with endometrioma, surgical removal of endometriomas increases the likelihood of conception in infertile women but also has the effect of diminishing ovarian reserve. In women with deeply infiltrative disease, one prospective cohort study assessing women with rectovaginal endometriosis evaluated pregnancy rates between those who underwent surgery and those who had expectant management. Pregnancy rates were equivalent in the surgical and expectant management groups [48].

Thus, the general approach to treatment of endometriosis is medical therapy for mild pain symptoms with surgery reserved for moderate to severe symptoms refractory to medical therapy or for circumstances precluding the use of hormonal therapy. The potentially radical nature of surgery and the associated risk of complications necessitates appropriate patient counseling prior to the decision to move forward with surgery. Women should be counseled that surgery may temporarily alleviate pain, but that recurrence is common. Women with infertility and significant pain are not hormonal therapy candidates and thus should be offered surgery. However, these patients should be counseled that pregnancy rates have not been shown to improve substantially after surgery and that assistive reproductive technology should be considered. Women with infertility who plan undergoing in vitro fertilization but significant anatomic distortion may also require surgery for anatomic restoration to facilitate safe oocyte retrieval.

Preoperative Assessment

The initial step in assessing a patient with suspected deep infiltrating endometriosis of the rectum involves taking a thorough history. Of particular importance is ascertaining whether or not the patient is experiencing any pain. This includes obtaining a detailed history on multiple components of pain including the location, severity, timing, and whether the pain is associated with any rectal bleeding. Pain associated with rectal bleeding is particularly concerning as it may be due to full thickness erosion of the rectum secondary to the endometriosis. Temporal relationship of pain with menses should be investigated as this may signal endometriosis, particularly DIE [49]. Dyspareunia and dyschezia are other symptoms that are frequently present in rectal endometriosis.

The next step in assessment includes obtaining a thorough surgical history. The purpose of this is twofold. First, it prepares the surgeon for adhesive disease from prior surgery, though DIE often presents as dense adhesions involving the colon, uterus, ovaries, fallopian tubes, and ureters. Second, and more importantly, it determines whether a minimally invasive surgical approach (MIS) is realistic. The presence of adhesions makes an MIS approach more difficult, and many surgeons will opt for an open approach if there is a significant history of surgeries. However, it should be noted that this practice varies from surgeon to surgeon based on preference and surgical expertise. As with taking any other surgical history, it is important to document the date of the surgery, the primary surgeon, and to note whether there were any complications in the surgery.

As part of the history, it is imperative to inquire about any family inheritance of colorectal conditions including, but not limited to, colon and rectal cancer, inflammatory bowel disease, and hemorrhoids. Any family history of cancer should also be fully explored in depth, whether the cancer is of a colorectal nature or not. Further questioning should also attempt to deduce whether the patient is suffering from any fecal incontinence (FI). Though FI is not particularly associated with endometriosis, it is an important consideration as low anterior resections (LAR) are associated with exacerbation of FI due to loss of the rectal reservoir.

After a thorough history has been obtained, the next step is an in-depth physical examination. In particular, the presence of any abdominal incisions should be noted, specifically checking around the umbilicus and for the presence of any smaller scars for past incisions. Tenderness to palpation or the presence of any palpable masses increases the suspicion for endometriosis. The most important aspect of the physical exam in these patients, however, is the digital rectal exam (DRE). This will yield a great deal of information about the patient. On this part of the exam, the surgeon may be able to palpate areas of endometriosis in addition to assessing the strength of the anal sphincter. The strength of the anal sphincter can be determined by having a patient bear down while the surgeon is performing the DRE. A bimanual examination will yield even further information, possibly revealing the presence of endometriosis in the rectovaginal septum or thickened uterosacral ligaments upon palpation. Lastly, a proctoscopy performed outpatient may allow the surgeon to visualize deeply infiltrating endometriosis, and how proximal it is relative to the anal sphincters. This ultimately will allow the surgeon to gage how low any future anastomosis will need to be.

Whether or not endometriosis is suggested based on physical examination, it is important to obtain imaging to further elucidate the extent of disease. As noted in the “Diagnosis” section earlier, transvaginal ultrasound (TVUS) is still the preferred starting diagnostic imaging study with a relatively high sensitivity [30, 50]. If transrectal ultrasonography is readily available, it should be offered [34], but more than likely MRI is the initial next step if DIE of the rectum is suspected [35]. Additionally, further imaging with the use of a colonoscopy should be obtained prior to any surgical intervention to rule out full thickness erosion or any other colonic pathology such as colon cancer or bowel stenosis.

If surgery is agreed upon, consent is obtained from the patient, and the surgeon should discuss shaving as well as LAR with a possible loop ileostomy [30, 51, 52]. If an ileostomy is considered likely based on the preoperative assessment, the patient should be counseled as such, and preoperative the ostomy site should be determined prior to surgery. Extensive counseling about shaving lesions, discoid resection, low anterior resection, and possible loop ileostomy should be discussed prior to surgery.

Surgical Technique

The goal of surgical management of endometriosis is to destroy or remove all visible lesions of endometriosis and to restore normal anatomy. For superficial lesions, either ablative or excisional procedures may be utilized. Ablative techniques include electrocautery or Argon Neutral Plasma Energy. Excisional techniques include sharp dissection of lesions and the involved peritoneum as well as respective procedures of the bowel, bladder, vagina, uterosacral ligaments, and ureters when invasive disease is present. Laparoscopic management of endometriomas and superficial endometriosis is considered the standard of care [42]. In addition, there are increasing reports of laparoscopic management of DIE, even in cases where bowel resection is necessary [53]. More recently, the benefits of a robotic surgical approach for the surgical management of endometriosis have been examined. Thus far, limited data suggests comparable outcomes between conventional laparoscopy and robotic-assisted laparoscopy, but a longer operating time [54]. Proponents of robotic surgery suggest that the design advantages of the robotic platform, such as stereoscopic three-dimensional visualization, increased range of movement, and enhanced surgeon comfort, enable surgeons to complete complex dissections necessary for the surgical management of endometriosis. In cases of rectal involvement, robotic assistance has been shown to be feasible and safe with comparable outcomes to laparotomy [55].

Gynecologic Approach to Robotic-Assisted Surgical Treatment of Endometriosis

For a robotic approach, ideal patient positioning is in low lithotomy with arms tucked at the side. A foley catheter is placed to gravity drainage and a uterine manipulator placed to allow for appropriate retraction of the uterus during the surgery. In cases with severe rectovaginal involvement, the ureters are often displaced medially by adhesive disease.

Urology is thus typically consulted for the placement of lighted ureteral stents to allow for identification of the ureters throughout the surgery. Several docking techniques have been reported. Both side docking and central docking are feasible. A Veress needle is used to achieve pneumoperitoneum and a 12 mm optical midline port, usually at the umbilicus, is placed under visualization. The ports utilized for robotic arms one and two are placed about 8 cm laterally and slightly caudad on either side of the port accommodating the robotic laparoscope. Arm 3 is set 8 cm to the left of the port for robotic arm 2. When necessary, a 5 or 12 mm assistant port placed in the left upper quadrant.

Once docking is completed, a monopolar scissor is placed in robotic arm 1, and a bipolar forceps is placed in arm 2. A grasping instrument is placed in arm 3. A careful exploration is undertaken to ensure all endometriotic lesions are visualized. Retroperitoneal dissection is often initiated lateral to the infundibulopelvic ligament with a cephalad to caudad approach. Careful traction and counter traction is utilized to incise the peritoneum. The incision is extended parallel to the infundibulopelvic ligament and the ureter is identified medially and dissected laterally, allowing for safe resection of the pelvic peritoneum involved with endometriosis. Similarly, a lateral to midline approach is utilized to create a plane between the ovaries, uterus, and rectum. If present, excision of uterosacral nodules and/or rectovaginal nodules is then completed. If rectal involvement is present colorectal is often consulted for management. One of three approaches may be utilized including shaving, discoid resection, and segmental bowel resection.

Colorectal Approach to Robotic-Assisted Surgical Treatment of Endometriosis

The discussion of optimal port placement and docking generally takes place prior to the surgery as the gynecologic surgeons are often initiating the case. A two operative arm approach is utilized in most cases, but rarely, an extra left-sided upper abdominal part can be placed to utilize all three arms.

The initial step in the surgery is identification of both ureters. A complete dissection and lateralization of the ureters is typically necessary for the gynecologic portion of the surgery and is performed by the gynecologic surgeon. Lighted ureteral stents placed by the urological service prior to initiation of the case can also facilitate identification of the ureters.

Based on degree of rectal involvement, a multitude of approaches can then be taken. If the endometriosis is occluding less than 30 % lumen diameter, the surgeon can try to shave off the areas of endometriosis. It is important that cautery is not used for shaving, and instead a surgical knife is utilized. Once shaven, the thin areas can then be oversewn to prevent tears from forming. An on-table colonoscopy can then be performed to look for leaks and thin areas under transillumination. If there is involvement of greater than 30 % of the lumen a formal lower anterior resection should be performed. Additionally, if the anastomosis is less than 6 cm from the anal verge, a divergence with a proximal loop ileostomy should be performed.

DIE generally obliterates the planes laterally and anteriorly along the rectum and thus, a posterior approach is used initially to avoid dense adhesions. Dissection beneath the upper rectum, just adjacent to the rectal mesentery to avoid inadvertent injury to nerve fibers emanating from the sacral promontory, allows access to the presacral space. Throughout the dissection, the left ureter, which has typically been dissected by the gynecologic surgeon, is traced medially as it traverses under the sigmoid and into the pelvis to avoid injury. With care to preserve the inferior mesenteric artery, the total mesorectal plane is completely dissected posteriorly beyond the coccyx. The lateral dissections are then completed until the rectum is released circumferentially. The final dissection is anteriorly as this is the area typically involved with endometriosis. Once the adhesions between the uterus ovaries are released, and the anterior rectum is visible, an assessment can be made as to whether a "shaving" technique of DIE is safe and feasible, or whether a formal resection is indicated. In our practice, the lesion is shaved if less than 30 % of the anterior wall of the rectum is involved. Visual haptics can facilitate the identification of the borders of the nodule of DIE. DIE is often fibrous and dense, creating a hard nodule, while the borders of the normal rectum are much softer in appearance. If a shaving approach is feasible, a sharp dissection is completed with a robotic scissor and interrupted 2-0 polyglactin 910 stitches are placed to imbricate the thinned area of rectum. If the endometriosis is invasive to the point where a full thickness excision is needed, but <30 % of the lumen is involved, a discoid resection is completed and interrupted 2-0 polyglactin 910 stitches are placed to close the defect. An intraoperative sigmoidoscopy is subsequently completed for both the shaving and discoid resection approaches to ensure an airtight repair.

If the endometriosis is deemed infiltrative and involves >30 % of the lumen, a resection procedure is completed. Dissection is completed both proximally and distally such that resection can be completed with margins uninvolved by endometriosis. Subsequently, the mesentery of the rectum is dissected distally and ligated with the robotic vessel sealer. The sigmoid and left colon are mobilized sufficiently to exteriorize the colon through a widened left lower quadrant port. The proximal transection is then completed through the abdominal incision with care to ensure margins are clear from endometriosis. A purse string stitch is placed around the circumference of the lumen. Intravenous indocyanine green 3 cc/10 mg is injected and the robotic Firefly system is utilized to ensure sufficient perfusion to the descending colon. A 29 EEA anvil is then placed into the descending colon and the purse string is tied down. An intracorporeal anastomosis is subsequently completed with a 29 EEA stapler. The anastomosis is checked using a sigmoidoscope and an air leak test is completed with the anastomosis under irrigation fluid. A diverting loop ileostomy is placed if the anastomosis is less than 6 cm from the anal verge.

Postoperative Care

Postoperatively, patients who undergo any colorectal procedure (shaving, discoid resection, or segmental resection) are admitted for close monitoring as they are at high risk for postoperative complications. In one cohort, 20 % of patients who underwent bowel resection for DIE experienced at least one major complication [48]. Among the most common is rectovaginal fistula. Patients are also at risk for pelvic infection and the need for reoperation should be counseled as such. Close follow-up by both the gynecologic and colorectal services postoperatively is imperative for optimal outcomes. With appropriate patient selection as well as coordinated and standardized care, a multidisciplinary approach to the management of DIE can optimize surgical outcomes and potentially lead to sustained remission of symptoms.

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Chapter 18

Anesthesia in Robotic Colon and Rectal Surgery

Christopher Schroff and Jason Sankar

Background

Laparoscopic, minimally invasive surgery has been performed since the early 1900s when Dr. Georg Kelling, a German surgeon, used a technique he called "koelioskopie" on dogs to utilize the pneumoperitoneum to stop intra-abdominal bleeding [1]. Then in 1910 a Swedish surgeon, Dr. Hans Christian Jacobaeus, was the first to use the technique on humans, which he called laparothorakoskopie [1]. Since that time, the technology of laparoscopy progressed, especially with gynecological surgeries, when in the 1960s and 1970s a German gynecologist, Dr. Kurt Semm, developed the automatic insufflator and hundreds of laparoscopic instruments [2]. However, it was not until 1982 that the solid-state video camera was utilized for laparoscopy and made the technique safe and practical for many surgical procedures [2]. Dr. Philippe Mouret, a French surgeon, performed the first laparoscopic cholecystectomy in 1987, and that same year scientists at Stanford began working on the "Telepresence Surgery System," the predecessor of today's Da Vinci surgical robotic systems [3]. The robotic system was developed to help solve some of the limitations of traditional laparoscopy and to further expand the technique's application in the world of surgery [3, 4]. As surgeries have evolved to incorporate this new technology, so have the anesthetic considerations.

A wide variety of laparoscopic procedures bring new proposed advantages of less postoperative pain, less opioid use, smaller incisions, decreased surgical stress, decreased wound complications, faster recovery times, shorter hospital stays, and reduced healthcare costs [5–8], but also bring about new challenges in delivering general anesthesia associated with CO_2 insufflation and steep trendelenburg positioning, such as hemodynamic changes, decreased urine output, and decreased pul-

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monary function [9–17]. With the addition of the surgical robot to laparoscopic surgery, a new set of anesthetic considerations and challenges have arisen during the preoperative, intraoperative, and postoperative period. Since robotic surgery is an extension of a surgeon's laparoscopic capabilities, it is crucial for the anesthesia provider and surgeon to first fully understand the physiologic changes and complications associated with laparoscopic surgery before tackling the additional concerns of the robot. We will briefly describe these issues before moving on to the specific robotic concerns for colorectal surgery.

Laparoscopic surgery and the pneumoperitoneum with CO_2 insufflation provide specific physiologic challenges affecting the cardiovascular, pulmonary, renal, and neurologic systems. The mechanical stress due to the stretching of the abdomen and chemical stress of the highly absorbable carbon dioxide lead to sympathetic stimulation and neuroendocrine response of increased catecholamines, renin, angiotensin, vasopressin, and cortisol [9–12], which greatly affects the cardiovascular system. The heart is met with a host of physiologic changes including an increase in systemic vascular resistance, an increase in mean arterial pressure, an increase in cardiac filling pressure, an increase in afterload, an increase in dysrhythmias, a decrease in cardiac index, and a decrease in venous return. Similar to the heart, the lungs have to also work against the mechanical stress of CO_2 insufflation. There is decreased lung volume, decreased lung compliance, increased airway resistance, as well as a displacement of the diaphragm cephalad, which can result in an endobronchial intubation [10, 11]. The mechanical and neuroendocrine stress of CO_2 insufflation also impacts the kidneys, resulting in decreased renal blood flow, decreased glomerular filtration rate, and low urine output [18]. Urine output, fortunately, returns to normal ~2 h after the resolution of insufflation, and as long as insufflation pressures are less than 15 mmHg, laparoscopy is safe in patients with renal disease [19]. Therefore, we are unable to reliably use urine as an indicator of volume status and end-organ perfusion interoperatively [20]. While the brain may be relatively far from the peritoneum, it is still unable to escape the effects of CO_2 insufflation. There is an increase in cerebral blood flow and an increase in intracranial pressure, making a laparoscopic procedure a concern for any patient with an intracranial mass or ventricular shunt [21]. Like intracranial pressure, intraocular pressure also increases with pneumoperitoneum, which raises concern for optic nerve ischemia, especially in the setting of high fluid administration and steep trendelenburg positioning [22]. While these physiologic changes are expected, there are several important complications associated with CO_2 insufflation that the surgeon and anesthesiologist must be well aware of and ready to handle.

Complications during robotic surgery are specifically related to the pneumoperitoneum with intraperitoneal CO_2 insufflation, extreme patient positioning, and surgical instrumentation. The complications from CO_2 insufflation include cardiopulmonary compromise, renal dysfunction, and hypothermia. Potential surgical complications involve CO_2 tracking to different spaces including subcutaneous tissue, thorax, mediastinum, pericardium, and gas embolism, as well as acute hemorrhage and bowel or bladder perforation [23]. Upper abdominal procedures, such as fundoplication and urologic procedures, have been found to have a higher rate of complications, especially when patients have multiple comorbidities [24–28]. Therefore, appropriate patient selection is crucial to minimizing risk associated with robotic surgery. We will first discuss preoperative anesthetic concerns regarding appropriate patient selection and interoperative monitoring before moving on to the special anesthetic concerns and considerations surrounding the interoperative and then postoperative period of robotic colorectal surgery.

Preoperative Concerns

Robotic surgery has some unique considerations and challenges such as longer operative times, large robotic systems with limited access to the patient, and the physiologic stress of pneumoperitoneum and extreme trendelenburg positioning [29], so selecting the appropriate patient is very important. As with any laparoscopic procedure with CO_2 insufflation, there are several physiologic stresses the patient must be able to tolerate; however, the extreme trendelenburg and longer procedure times make these stresses more of a concern.

Patient Selection

As mentioned earlier there are several physiologic stresses on the heart that make the preoperative cardiovascular evaluation important, especially if a patient gets shortness of breath or chest pain with exercise less than 4 mets. From a pulmonary perspective the insufflation pressures and the steep trendelenburg can make it difficult to generate adequate tidal volumes, especially in very obese patients. Therefore, ventilator settings must be adjusted to minimize the high peak airway pressures as much as possible. As we stated before there is a drop in urine output interoperatively for a variety of reasons related to the pneumoperitoneum, but this returns to normal ~2 h after insulation and appears safe in renal patients as long as insufflation is less than 15 mmHg [19]. Robotic surgery would not be appropriate for patients with any concern for increased intracranial pressure such as intracranial masses or ventricular shuts, due to the pressure from insufflation and steep trendelenburg, which reduces venous return [21]. For similar physiologic reasons, patients with concern for high intraocular pressures are poor candidates for robotic surgery [22].

Monitoring and Vascular Access

Planning for monitoring the patient intraoperatively during a robotic surgery has a few unique considerations beyond the typical comorbidities of the patient. Since urine output may be low, or may not be indicative of volume status in robotic surgery, one may want to consider an arterial line in addition to standard ASA monitors. This would allow continuous blood pressure monitoring as well as volume status by way of respiratory variation or more specifically with stroke volume variation, using a Flotrac arterial transducer [30–32]. Volume status may also be measured with a central line and monitoring central venous pressure; however, it has been shown that using a Flotrac arterial transducer to measure stroke volume variation is just as accurate and may eliminate the need for placing a central line [31]. Volume status and fluid management is very important in robotic surgery as the steep trendelenburg positioning makes patients prone to facial, pharyngeal, and laryngeal edema, which could compromise the patient's airway in the immediate postsurgical period [29]. Furthermore, a few studies have shown that fluid restriction may improve outcome after major elective gastrointestinal surgery [33]. Careful planning of the necessary monitors is important because the patient is carefully positioned for the robot with both arms tucked and secured with a beanbag; therefore, access to the patient intraoperatively is very limited and would require stopping the surgical procedure and carefully undocking the robot and deflating the beanbag, before being able to place an invasive monitor.

For the same reasons, adequate vascular access for potential emergent large volume resuscitation and medication administration needs to be established prior to final positioning of the patient. Central access is not necessarily needed for robotic surgery unless patient is a difficult peripheral IV placement, surgeon/anesthesiologist want CVP monitor for volume status, or patient's comorbidities place patient at a higher risk for needing centrally administered medications. Two large bore peripheral intravenous lines should be sufficient, and if need for central access is determined emergently, the neck would be exposed and available for an external jugular peripheral IV or internal jugular central line during the case.

Intraoperative Concerns

Simply put, the goals of anesthesia are to optimize intraoperative conditions, provide rapid recovery, and minimize complications. General anesthesia with an endotracheal tube, muscle relaxation [34], and mechanical ventilation [35] provides the optimal working environment for the surgeon and safety for the patient [36, 37] undergoing robotic surgery. Faster recoveries and shorter hospital stays have been shown with minimally invasive and robotic surgery [5–8]; however, adequate pain control beginning in the perioperative period is crucial to continued pain control in the postoperative period. Pain control will be discussed in more detail in the postoperative section, as it is the major anesthetic concern during that time to help expedite recovery. Here we will focus on complications associated with robotic surgery due to pneumoperitoneum and extreme trendelenburg positioning, which the surgeon and anesthesiologist must recognize and deal with quickly.

Cardiopulmonary Complications

In addition to the physiologic cardiopulmonary changes with robotic surgery as described earlier, these patients are prone to cardiac dysrhythmias from increased vagal tone from peritoneal stretch and hypercarbia causing bradycardia and tachycardia, respectively [29]. In rare events they are also susceptible to complete cardiovascular collapse from profound vagal response, cardiac dysrhythmias, excessive intra-abdominal pressure, tension pneumothorax, cardiac tamponade, CO_2 embolism, acute blood loss, myocardial infarction, and respiratory acidosis [29]. These patients are also vulnerable to hypoxemia from endobronchial intubation from the cephalad movement of the carina with insufflation and trendelenburg positioning [38, 39].

Subcutaneous Emphysema and Potential Sequela

Inadvertent extraperitoneal insufflation in the subcutaneous, preperitoneal, or retroperitoneal tissue can result in subcutaneous emphysema [40, 41], which is a risk of any laparoscopic procedure. Subcutaneous emphysema usually resolves on its own after deflation of abdomen; however, in some cases it has been shown to cause persistent hypercarbia in the recovery room [42], or extend to certain fascial compartments, such as the thorax and mediastinum, leading to hemodynamic instability from a tension capnothorax or cardiac tamponade, respectively [43]. CO_2 can fill the fascial planes contiguous with the abdomen, chest, neck, and groin, and if subcutaneous emphysema extends to the chest and neck, it can then extend into the thorax and mediastinum [44]. Operative times of >200 min and use of six or more surgical ports increases the risk for subcutaneous emphysema [41], and subcutaneous emphysema can often be detected by crepitus or a sudden increase in end tidal CO_2.

As previously mentioned, subcutaneous emphysema usually resolves on its own, but if persistent hypercarbia occurs despite hyperventilation, it may be necessary to deflate the abdomen and reinsufflate at a lower pressure. And if the CO_2 tracks into the thorax, mediastinum, or pericardium, the cardiopulmonary repercussions [43, 44], such as tension capnothorax or cardiac tamponade, must be quickly recognized and treated with appropriate supportive care until the CO_2 is evacuated from the thorax, mediastinum, or pericardium.

Capnothorax is a rare potentially life-threatening condition, which is most common with procedures near the diaphragm [23, 24, 45]. It may present as unexplained increased airway pressure, hypoxemia, hypercapnia, surgical emphysema, and if tension capnothorax occurs, it may present as severe cardiovascular collapse [43]. Treatment includes deflation of the abdomen with supportive care. If there is minimal physiologic compromise, conservative treatment with close observation may be sufficient as CO_2 is rapidly absorbed [43, 46, 47]. However, if tension capnothroax with hemodynamic instability occurs, a chest tube may be necessary. Now capnomediastinum and capnopericardium are very rare, but if they occur, they can cause drastic hemodynamic compromise, requiring supportive care until the CO_2 dissipates or is manually extracted.

CO_2 Embolism

While CO_2 can travel to several tissue spaces as mentioned earlier, it can also travel to the blood, and in a large enough quantity it can cause a CO_2 gas embolism. CO_2 embolisms have been well documented to have a high incidence in laparoscopic surgeries, but usually not having significant cardiopulmonary effects [48, 49]. Signs of CO_2 embolism may include cardiac arrhythmia, hypoxemia, and hypotension, and an associated decrease in $ETCO_2$ from a decrease in cardiac output, similar to any type of embolism. Because of the outflow obstruction caused by the embolism the EKG may show a right strain pattern and widening of the QRS complex. Or if the obstruction is preventing inflow back to the right heart from the head, one may see cyanosis of the head and neck. Furthermore, a patent foramen ovale or an atrial septal defect may result in paradoxical CO_2 embolism to the brain. As with other CO_2-related complications, if the patient is unstable, the abdomen should be deflated and patient should be hyperventilated to promote rapid CO_2 washout while providing supportive care. However, the patient should also be turned to the left lateral decubitus with a head-down position to allow the gas to rise into the apex of the right ventricle and prevent pulmonary artery outflow obstruction. Hyperbaric oxygen has also been used to help treat CO_2 embolisms [29].

Hypothermia

While little of the abdominal contents are directly exposed to the cold operating room environment in robotic surgery, patients are at the same risk of hypothermia as an open procedure. This is thought to be related to the convention loss of heat from the dry cool CO_2 (21C), being continuously pumped into the peritoneum [50–52]. Appropriate warming of patient with convection-based warming blankets and fluid warmers may be necessary, especially for long procedures seen in robotics.

Positioning Complications

The long procedures also make patients susceptible to several complications related specifically to positioning. As we have alluded to several times in this chapter, the steep trendelenburg position and the increased intra-abdominal pressures can impact the airway by increasing peak airway pressure, increasing upper airway edema, and potentially cause a right mainstem or endobronchial intubation with diaphragm and mediastinum shifting cephalad. However, prolonged caudal displacement of the shoulder can lead to brachial plexus injury, so adequate padding of the shoulders prior to final positioning with the beanbag is essential [53]. Furthermore, the lithotomy positioning makes the patient susceptible to peroneal nerve injury resulting in foot droop, which again requires proper padding and inspection prior to final positioning. This positioning also further puts the patient at risk for a deep vein thrombosis from venous stasis [54], and sequential compression devices used during the procedure and early ambulation in the recovery period will help minimize this risk.

Surgical Injury

With any surgery there is the risk for inadvertent vascular or organ injury, and robotic surgery is no different. However, specific risks similar to laparoscopic surgery exist. These include GI, bladder, or vascular injury from a trocar or Veress needle. In order to minimize risk of perforating GI or bladder, the stomach and bladder should be decompressed with a gastric tube and foley catheter, respectively. Furthermore, if a vascular injury occurs acute blood loss may be difficult to see within the view of the camera port, so acute blood loss needs to be high on the differential for any unexplained hypotension, and if there is major bleeding the surgeon must convert to open [29]. Communication between the anesthesiologist and surgeon is key to ensuring patient safety during any surgery, but with the surgeon in a control station away from the patient in robotic surgery, it makes the need for good communication even more imperative.

Appropriate Surgical Environment

Good communication is not only for the just the surgeon and anesthesiologist, but for the entire operating room staff. There are more moving parts in a robotic surgery that require a well coordinated and flexible staff to ensure the case runs smoothly and safely. Operating room staff familiarity with equipment will help minimize operating time, minimize time to convert to open, and minimize time to expose patient in the event of a code. However, like with any emergency situation, preparedness and practice are what enable people to respond quickly and efficiently, and save those precious seconds that might save a patient's life. With the initiation of any new robotic program, all staff should be taken through emergency scenario simulations, and these simulations should be repeated at least annually, if not biannually, to ensure staff familiarity. In addition to the staff needing to be familiar with all the bulky equipment of the robot, it is important that the operating room has the space to accommodate all of the equipment. Equipment should be strategically placed to facilitate patient access if needed [29].

Postoperative Concerns

Rapid recovery is a major goal and advantage of robotic surgery, and much of that is dependent on adequate pain control initiated from the beginning of the procedure and continued into the postoperative period. While laparoscopic procedures like robotic surgery have been shown to have less incisional pain [55], they do have a significant amount of visceral pain.

Multimodal Approach to Pain

Adequate pain control is crucial to early ambulation [56] and a multimodal approach has proved to provide superior pain control, while minimizing side effects of any one type of pain medication [55, 56], especially the ileus, nausea, and altered mental status from opioid pain medication. For instance, nonsteroidal anti-inflammatory drugs have been shown to reduce postoperative pain and opioid requirements [57], and when combined with acetaminophen pain control is better than either by itself [58–60]. Glucocorticoids can also be considered since they have been shown to reduce postoperative pain and length of hospital stay after abdominal surgery with no increase in complications, including after colorectal surgery [61, 62]. Ketamine, an NMDA antagonist, has also been shown to have some benefit [63]; however, some patients may not be able to tolerate the vivid dreams or hallucinations associated with it.

Local Anesthetics

Long-acting local anesthetic infiltration at port sites has also shown to be beneficial [64–68]. However, need for continuous infiltrative local anesthetic via a transversus abdominis plane (TAP) block is usually not necessary unless the surgery is converted to open, and the TAP block can only cover pain below the umbilicus. Furthermore, intravenous lidocaine has been shown to reduce postoperative pain and opioid requirements, improve bowel function, and reduce the length of hospital stay [69–71]. Intravenous lidocaine reduces opioid requirements, minimizing postoperative ileus, but it also improves bowel function by improving intestinal perfusion and reducing gastrointestinal irritation through anti-inflammatory properties of the local anesthetic. Unfortunately, there is no optimal dose, and with concerns for local anesthetic toxicity, intravenous lidocaine should remain a backup if other options are not feasible [29]. Postoperatively, epidurals would provide excellent pain control and improve GI motility via a T6-L2 sympathectomy; however, with small incisions in robotic surgery the need is not there, and the epidural would only take away the advantage of early ambulation in robotic patients. While pain is a major concern for rapid recovery, postoperative nausea and vomiting (PONV) is not far behind.

Postoperative Nausea and Vomiting

While the multimodal approach to pain control will help minimize the nausea and vomiting associated with narcotics, all laparoscopic surgeries are at an increased risk of PONV [72]. Thus, the inability to take pain medications and nutrition by mouth will inevitably slow one's recovery from a robotic colorectal surgery. Like the treatment of pain, PONV should be treated with a multimodality approach, including adequate hydration, glucocorticoids, scopolamine patch, and 5-HT3 antagonists, while minimizing the amount of opioid pain medication [72–74].

Conclusion

Anesthesia and surgery are inseparable; as surgery changes, so must the anesthesia we deliver. Surgery and anesthesia are like any team. Their goals are one in the same and working seamlessly together to accomplish common goals is crucial to a successful procedure. Optimizing intraoperative conditions, providing rapid recovery, and minimizing complications are common goals of any surgical procedure. Robotic surgery is no different.

In order for the team to achieve its goals, each member of the operating room must be familiar and understand the physiologic changes and potential complications associated with the large robotic systems and the physiologic stress of pneumoperitoneum with extreme trendelenburg positioning. While it is important each member of the operating room understand these potential issues, it is also crucial each member comes prepared and communicates effectively to ensure the patient is treated in the most effective and safe manner. Each operative team is only as strong as their weakest link, and the team extends beyond the immediate operating room staff. It includes pre and postoperative nursing, family and friends, as well as the patients themselves. We live in an exciting time for surgical advancements, and the ability to adapt to these changes by everyone will ensure these advancements are successful and continue to lead to new improvements in healthcare.

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Chapter 19
Single-Incision Robotic Colon Resection (SIRC)

Yen-Yi Juo and Vincent Obias

Introduction to Robotic Single-Port Approach

Laparoscopic Single-Site Surgery (LESS) is an advanced laparoscopic surgical approach, hypothesized to decrease port-related complications, recovery time, incisional pain, and improve cosmesis. According to the consensus statement of the Consortium for Laparoendoscopic Single-Site Surgery from 2010 [1], colon resection, along with cholecystectomy, appendectomy, and inguinal hernia repair, was listed as a general surgical procedure anticipated to become high-volume LESS procedures. Multiple single-institution case series as well as a meta-analysis comparing LESS colorectal surgical procedures to their conventional multiport laparoscopic counterparts demonstrated equivalent overall outcomes, rates of conversion to open surgery, oncologic outcomes for tumor resection, but decreased blood loss, hospital stay, and incision size. However, the prevalence of single-site laparoscopic colon resection has been limited by its technical challenges. The procedure is associated with limited triangulation and retraction capabilities stemming from confined optics and crowded instruments working along a single axis. While pioneering surgeons were coming up with solutions to these technical challenges, i.e., as the use of a combination of bariatric and conventional instruments of different lengths to avoid hand crowding or the use of ancillary 1.9 mm needle ports to enhance retraction, many inherent difficulties remain as a result of attempting to perform LESS using a set of technologies and instruments designed primarily for multiport laparoscopic procedures.

The introduction of a stable, multitasking robotic platform to LESS with its unique ability to intracorporeally cross and switch the two articulated instruments represents a paradigm-changing advance. Only a handful of procedures have successfully spread using a robotic single-site approach, such as cholecystectomy, hysterectomy,

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and colon resection. The U.S. Food and Drug Administration (FDA) only approved the single-port platform for the robotic da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) for the use of cholecystectomy in the field of general surgery. SIRC is being performed on an elective basis in multiple major colorectal centers with several published case series. While previously hypothesized benefits of a robotic LESS approach over its conventional multiport laparoscopic counterparts have yet to be proven with adequately powered prospective studies, early studies have proven that they are at least safe and feasible procedures with equivalent perioperative outcomes such as operative time, complications, and length of stay. This chapter focuses specifically on robotic single-site colectomy (SIRC), including detailed descriptions of its devices, techniques, and specific procedure-related issues from findings in the literature and our institutional experience.

Single-Port Devices and Instruments

The key difficulties of LESS colectomy stem from the crowded placement of instruments through a single small incision and the resultant clashing of instruments, both intracorporeally and between the surgeons' hands, and the resultant poor visualization due to the instrument shaft obstructing the camera visual field. In order to solve these technical difficulties, SIRC offers two major infrastructural advantages: (1) the use of a single-site fascial access device, and (2) the "crossed-arm" feature of the robotic console.

Before the invention of the single-site fascial access devices, LESS used to be plagued by instrument crowding at the incision site and constant loss of insufflation during the procedure. Two major types of single-site fascial access device exist for LESS: a gel-based device (GelPOINT Advanced Access system and GelPoint Laparoscopic System, Applied Medical, Rancho Santa Margarita, CA) and a solid port (SILS Port, Covidien, Mansfield, MA; Quadport, Olympus, Center Valley, PA; Single Port Access Device, Ethicon, New Brunswick, NJ). Both have been described for use in SIRC, as well as a customized access point made from Alexis wound retractor and surgical glove [2]. The main requirements of the single-site fascial access device are that it should be able to maintain insufflation, allow ventilation during electrocautery to optimize visualization, and accommodate three to five ports that are 5–15 mm in size.

The second major technologic innovation that allows SIRC is the "crossed-arm" feature of the robotic console. After the two robotic instruments are docked and introduced into the abdomen through the single-site fascial access device, they cross each other under the abdominal wall. This facilitates both an improved range of motion and triangulation for both instruments and solves the poor visualization marred by the camera constantly "looking down the shaft of the instrument." This technique is only made possible by the extra articulation unique to robotic instruments and the robotic platform's ability to allow the surgeon to switch the control of the right-sided instrument to his left hand and the left-sided instrument to his right hand.

While Intuitive Surgical offers da Vinci single-site instruments specific to cholecystectomy, hysterectomy, and salpingo-oophorectomy, there are no special equipment required for SIRC besides those used for the performance of robotic multiport colon resection, namely, an assortment of graspers, Maryland dissector, suction irrigation, vessel sealer, vascular stapler, and cautery hook.

Preoperative Patient Evaluation and Preparation

The ideal patient for SIRC is one that is receiving the procedure for an elective indication, is not morbidly obese, is not actively inflamed, has no significant comorbidities, and does not have a history of prior abdominal surgery or radiation. While these conditions appear to apply to any general abdominal surgical candidate, it is especially relevant in SIRC due to the less than ideal triangulation and visualization the surgeon should expect from a single-incision procedure. SIRC has been performed for both benign and malignant indications with equivalent short-term oncologic outcomes, although data requiring long-term oncologic outcome from SIRC is still pending.

Depending on the indication and patient condition, preoperative mechanical bowel prep is recommended or not. Five thousand units of subcutaneous heparin and 12 mg of oral alvimopan (Entereg) are usually given in the preoperative area if there are no contraindications. Preoperative antibiotics are given in the operation room upon induction of general anesthesia.

Operative Technique

Positioning and Umbilical Access

The umbilical incision offers improved cosmesis by having the incision hidden in the near vicinity of the umbilicus. The umbilicus is also the location on the abdominal wall with the shortest distance from skin to peritoneum. For these two reasons, the majority of published accounts of SIRC described accessing the abdomen through an umbilical incision. The length of the infraumbilical skin incision is usually 3–4 cm. This is dictated by the orifice required for eventual specimen extraction. This provides justified rationale for a single-incision approach in colon resection, whereby we are not accumulating three separate small incisions into a larger incision, but simply reducing the total number of incisions without making an incision that would otherwise be larger. However, specimen extraction through the umbilicus, or through any midline incision in a laparoscopic procedure, is associated with a significantly higher incisional hernia rate [3]. This prompts some centers to attempt SIRC through a paramedian suprapubic incision [4]. This approach is suited for most SIRC procedures where only half of the abdomen has

Fig. 19.1 Z-shaped transumbilical skin incision. In order to decrease stretching at the skin level with the single-incision access device, a 3–4 cm. Z-shaped transumbilical incision was made instead of the traditional vertical incision

to be accessed, such as right hemicolectomy, left hemicolectomy, or sigmoidectomy, with the only contraindication being a total colectomy, where both sides of the abdomen must be accessed.

Patients are placed either supine or in lithotomy position on the operation table with both arms tucked, to facilitate docking of robot on the side of the surgical area and to enhance ergonomics for the robotic assistant on the opposite side of the patient area. It is of paramount importance to ensure that the patient is adequately secured to the operation table before prepping and draping of the patient. The relative position of the robot to the patient, once docked is immobile for the entire duration of the case, unless effort is made to undock, adjust, and redock the robot. Our institution advises securing the lower extremities with a safety belt across the thighs and taping the chest of the patient onto the surgical table with a foam pad to avoid skin abrasion.

A vertical infraumbilical or Z-shaped umbilical incision (see Fig. 19.1) measuring 3–4 cm is made with a scalpel, followed by dissection down to the fascial level. Once the fascia is exposed enough to allow secure grasping with a Kocher clamp (see Fig. 19.2), a small incision on the linea alba is made and the peritoneum entered under direct visualization. The peritoneal cavity is usually inspected to ascertain the lack of injury to underlying viscera nor other unexpected adhesion before the extending the fascial incision to allow introduction of the single-incision access device (see Fig. 19.3).

Trocar Placement and Robot Docking

Typically four trocars are placed through the single-incision access device (see Figs. 19.4 and 19.5). A 12-mm trocar for the robotic lens in the middle, two 8-mm trocars (arms 1 and 2) for each of the robotic arms to each side of the lens, and an additional 5-mm trocar for the robotic assistant. At the time of insertion, trocars

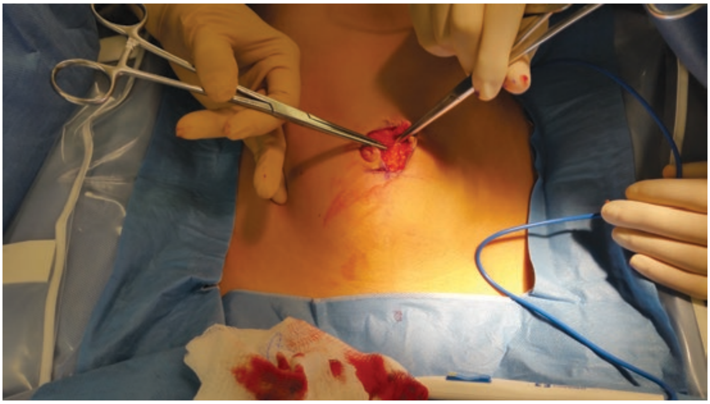

Fig. 19.2 Entry into peritoneum under direct visualization. After dissecting down to the level of the fascia under direct visualization, the operators grasp the fascia with two Kocher clamped and elevate the peritoneum away from the bowels before sharply incising and entering the peritoneum

Fig. 19.3 Placement of the single-incision access device. The single-incision device protects wound edges from undue tension during the procedure and also places gentle traction radially around the incision to allow maximal utilization of the 3–4 cm incision. The two strands of the fascial stay suture are placed upon initial entry into peritoneum in order to facilitate wound closure at the end of the procedure

should be placed aiming perpendicular to the skin level toward the center of the single-incision access device instead of in the direction of the target organ. This avoids excessive torsion on the incision during the procedure and also allows a greater range of motion for the instruments, which would otherwise lie close to the abdominal wall. If possible, have the thick black line at approximately the level of the peritoneum to reduce tension at the crossed arm areas. But, the thick black line can also be slightly above if more length is needed externally to separate the arms. We also use long bariatric trocars to keep arms 1 and 2 further away from each other.

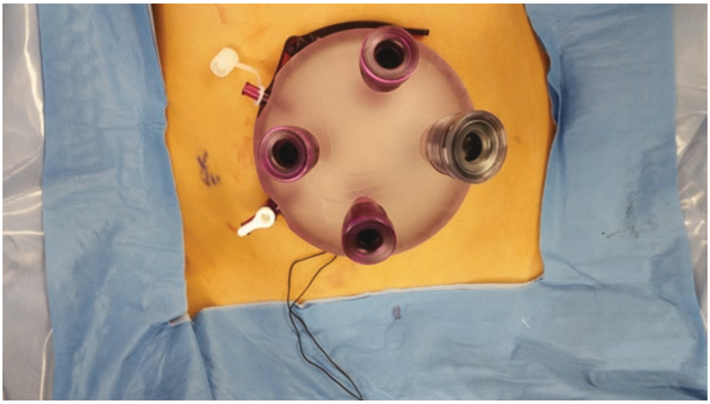

Fig. 19.4 Configuration of trocar placement on the single-incision access device. On the Applied Gel Point cap, 4 applied trocars are placed in a diamond configuration. The camera is placed through the port closest to the side of the colon intended for resection, while the two robotic working arms go through the cephalad and the caudal ports. The port farthest from the intended colon segment is used as the laparoscopic assistant port to allow maximal range of motion

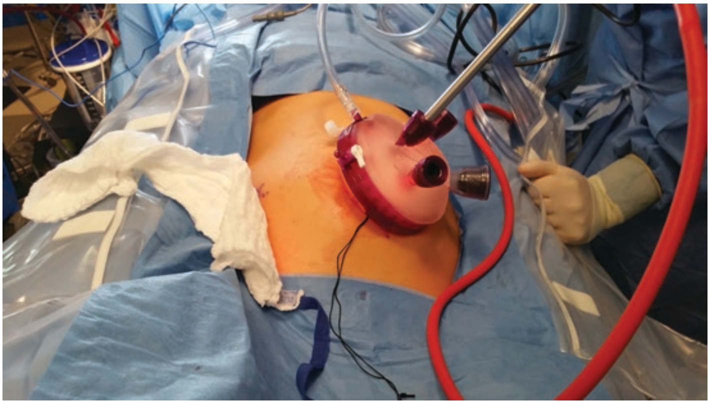

Fig. 19.5 Intraoperative configuration of single-incision access device during right hemicolectomy. The abdomen is inflated through a side port on the Applied Gel Point. The patient's head is oriented toward 12 o'clock of the photo while the feet are at 6 o'clock of the photo. The operative bed is tilted to the left with slight reverse Trendelenburg. The camera placed through the camera port near the patient's right for initial inspection and preliminary lysis of adhesions before robot docking

A 30 up positioned camera is then positioned underneath and between the two arms. This allows the surgeon to view the procedure between the two instruments, with the instruments coming from above into view. We then manually switch arm 1 from the left hand to the right hand, and manually switch arm 2 from the right hand, to the left hand. Since the arms are crossed, the right hand will be controlling what appears to be the robotic right hand intraperitoneally, even though it is really the left arm crossing over and vice versa.

We use the Applied Gel Point that is used for single-incision surgery (see Fig. 19.4). The robotic 8 mm trocars can all go through the applied trocars. At the start of the case, we place four of the applied trocars in a diamond configuration, with one of the points aiming at the right colon. At the top of the diamond closest to the right colon, the camera is placed. Arm 1 goes into the caudal port and arm 2 goes into the cephalad port. The port farthest from the right colon can be used as an assistant port. The assistant is mainly used for suction and retraction. This assistant is unique in SIRC as assistant ports are not generally used in SILS.

The robot is typically docked to the side where the intended anatomic site is located. For example, the robot will be docked perpendicularly from the patient's right side for a right hemicolectomy and from the patient's left side for a sigmoidectomy, with the robotic assistant standing to the opposite side.

Right hemicolectomy

For a right hemicolectomy, the robot is docked perpendicular to the patient, with the patient in slight trendelenburg position and airplaned to the left. This allows the omentum to be placed easily over the transverse colon, while the small bowel is left in the pelvis. This also allows the surgeon to see the root of the mesentery of the right colon and facilitates a medial-to-lateral dissection. A long grasping retractor is placed in arm 2 to assist in triangulation. A vessel sealer is placed in arm 1 for tissue manipulation, blunt dissection, and vessel ligation.

We start by grasping the cecum and tenting it up toward the right lower abdominal wall. With the cecum tented up, we are able to identify the ileocolic artery. We score underneath the artery and begin our blunt medial-to-lateral dissection. Once the duodenum is identified near the base of the ileocolic artery, we then use the vessel sealer to transect the artery. Care is taken to avoid injuring the duodenum. We can then carry our dissection in a cephalad direction until the right branch of the middle colic is encountered and transected. At this point, we have transected all the major arteries needed for our right colectomy.

We next bluntly separate the mesentery of the right and transverse colon from the retroperitoneum. This medial-to-lateral dissection is done under direct vision. Sometimes we can completely separate the right colon and proximal transverse colon and gain access into the lesser sac and dissect through the right white line of Toldt.

If this has not been the case, we will finish our medial-to-lateral dissection and separate the omentum from the transverse colon, gaining access into the lesser sac. We then enter our previous dissection plane to the right of the duodenum and fully mobilize the hepatic flexure. The right white line of Toldt is then mobilized in a top-down manner. Lastly, we mobilize the cecum and distal small bowel mesentery completely off the sacral promontory. It is very important to mobilize the ileal mesentery off the sacral promontory close to midline in order to facilitate subsequent exteriorization and extracorporeal anastomosis. Once all the mobilization is done we also use the vessel sealer to transect the mesentery of the ileum 10 cm from the

Fig. 19.6 Z-shaped skin incision at the end of procedure. The 3-cm skin incision does not appear significantly bruised or erythematous at the end of the procedure due to the release of tension on the skin level provided by the Z-shaped incision

ileocecal valve and transect the mesentery of the transverse colon at the appropriate distal margin. This helps reduce the risk of mesentery avulsion and bleeding that can occur with exteriorization and anastomosis.

At this point, the entire intra-abdominal portion is done. We then exteriorize the right colon through the gel point base which acts as a wound protector. The small bowel and transverse colon are transected with a GIA stapler. The specimen is opened in the back table to inspect margin. In order to determine appropriate perfusion of transected intestine ends, 3–4 cc (8–10 mg) of ICG is injected intravenously. Using the robotic camera with the Firefly view, the transected bowel ends are inspected and any area of hypoperfusion is transected if noted.

Once the perfusion of intestinal ends is deemed appropriate, an anatomic side-to-side functional end-to-end anastomosis with a 75 mm stapler and a 55 mm transverse stapler is fashioned. The anastomosis is then placed back into the abdomen and the fascia is closed with 0 PDS sutures in figure of eight fashion (see Fig. 19.6).

Left Hemicolectomy

The patient is placed in Trendelenburg position and airplaned to the right. If the splenic flexure needs to be mobilized, many times it can be mobilized in this position. If the bowel is in the way, then a double dock is done with the patient placed in reverse Trendelenburg position during splenic flexure mobilization.

Once the robot is docked, we lift up the sigmoid colon and identify the mesentery medially underneath the upper rectum/sigmoid colon. We begin by scoring the mesentery in this area and bluntly dissect in a lateral fashion separating mesentery from retroperitoneum. Care is taken not to injure nerves lying on top of the sacral promontory near the base of the inferior mesentery artery. Effort is made to identify and protect the ureter. We isolate the Inferior mesenteric artery and ligate it with the vessel sealer. We then continue our medial-to-lateral dissection separating the left colon from the retroperitoneum. Eventually we come close to the ligament of Treitz and the inferior mesenteric vein is identified. We transect the vein with the vessel sealer. We continue our medial-to-lateral dissection over the tail of the pancreas, separating the splenic flexure from its deep attachments. This maximizes our medial-to-lateral dissection. At times, we can also gain access into lesser sac, and if this is achieved, all the attachments to the left of the access point into the lesser sac can be transected safely, further mobilizing splenic flexure.

After maximizing our medial-to-lateral dissection, we begin our lateral-to-medial dissection. The white line of Toldt is identified by its purplish hue. The white line of Toldt is opened up in a caudal to cephalad fashion. The splenic flexure mobilization is not finished until we gain access into the lesser sac. At this point, the only attachments left are between the omentum and the transverse colon which we divide with a vessel sealer.

After the entire left colon is fully mobilized, the ureter is again identified laterally. We transect the mesentery of the sigmoid colon/upper rectum with the vessel sealer at the appropriate distal margin. We remove arm 1 trocar and replace it with the robotic 13 mm stapler port to dock the stapler. We then transect the upper rectum with the robotic stapler. The robot is undocked and the colon is exteriorized through the base of the applied gel point, which acts as a wound protector. At the appropriate proximal margin, the mesentery is transected. The descending colon is assessed for perfusion using ICG and Firefly as discussed earlier. A purse string is placed in the end of the colon and a 29 EEA staple anvil is introduced per rectum. The colon is placed back into the abdomen. If more length is needed, the patient can now be placed in reverse Trendelenburg position and the robot redocked to mobilize more of the splenic flexure. After adequate length is obtained, a tension-free end-to-end anastomosis is fashioned utilizing the EEA stapler. The abdomen is irrigated, and the anastomosis is inspected for air leak while submerged under water and the rectum is insufflated with air. The midline incision is then closed with 0 PDS sutures in a figure of eight fashion.

Closure of Incision and Wound Care

The closure and wound care method is similar to conventional laparoscopic procedures. After ensuring adequate hemostasis and verifying absence of air leakage across anastomosis, the robot is undocked, the single-incision access port removed, and the fascial defect is closed in a running fashion with 1–0 monofilament absorbable suture. The skin is approximated with running subcuticular suture using a 4–0 monofilament absorbable suture, reinforced with Steristrips placed in a vertical manner across the incision. The patient is usually advised to remove the dressing and begin showering on postoperative day 2.

Postoperative Care

After undergoing SIRC, patients are typically admitted to regular surgical floor with Patient-Controlled Analgesia (PCA) for pain control and kept nothing by mouth (NPO) until demonstration of return of bowel function. Patient continued to receive oral alvimopan 12 mg (Entereg) twice daily beginning the day after surgery for a maximum of 7 days or until discharge. Efforts are made to remove Foley catheter and encourage ambulation as early as possible. Patients can usually ambulate on postoperative day 1 and begin passing flatus or bowel movement by postoperative day 2–3. They are usually discharged as soon as they can tolerate a low-residual diet and pain is under control with oral pain medication, provided there are no obvious postoperative complications.

Procedure-Specific Complications

Most complications occurring after SIRC does not differ significantly from either conventional multiport laparoscopic colectomies or multiport robotic colectomies. These include superficial and deep surgical site infections, hemorrhage, ureteral injury, unintended enterotomy, anastomotic leakage, thromboembolic events such as deep vein thrombosis, pulmonary embolism, stroke, myocardial infarction, and prolonged ileus.

Despite similar superficial surgical site infection incidence, an increased incisional hernia rate (10.2 %) in comparison with conventional multiport laparoscopic colectomy was observed among patients who underwent SIRC. Obesity appears to be the single most significant risk factor associated with development of incisional hernia following SIRC in our early case series [8]. It does not appear that the slightly longer umbilical incisional length is the culprit. With conventional multiport laparoscopic colectomy, although an umbilical incision about only 1 cm was made initially, the incision is usually extended to about 5 cm for exteriorization of colon or extraction of specimen. A recent study by Delaney et al. [3] on laparoscopic colorectal procedures cited an incisional hernia rate of 8.9 % among midline extractions versus 2.3 %, 3.8 %, and 4.8 % for muscle splitting, Pfannenstiel, and ostomy site extractions, respectively. Several previous studies have come to similar conclusions regarding a higher incisional hernia rate after midline extraction after laparoscopic colectomy [9, 10].

A rare but remarkable complication arising from SIRC is subcutaneous emphysema that is generalized or restricted to certain anatomical locations such as the groin.

This is a known complication from pneumoperitoneum induced during laparoscopic procedures [5], with loose fitting cannula/skin and fascial entry points, use of cannulas as fulcrums, torque of the laparoscope, procedures lasting >3.5 h, and robotic fulcrum forces being commonly cited risk factors [6]. Besides frequently meeting all previous described risk factors, it generally takes the operating surgeon longer to realize the trocars have been displaced during robotic procedures due to the increased physical distance between the surgeon and the patient, allowing more time for air to dissect into unintended tissue planes. While the physical finding is usually striking when this complication occurs, with generalized crepitus involving the patient's face, torso, and limbs, the condition usually spontaneously resolve within a week or two with no significant sequelae. Subcutaneous emphysema is seen in multiport surgery as well and not restricted to just SIRC.

Outcomes

To date, there is no comparative study between SIRC and multiport laparoscopic colectomy and outcome data is based on a handful of small case series [7], with our institution providing the largest case series to date [8]. In fact, many argued that a multi-institutional randomized trial at such an early stage in the procedure's development might not provide definitive conclusions due to lack of standardization of surgeon's expertise with the procedure, as a wide variability in surgeon experience with the robot is expected.

So far, only seven accounts of SIRC have been published in the literature, with patient number ranging from 1 to 59 patients. The two largest series are those by Lim et al. and those from our institution. Lim et al.'s study involved 22 patients who underwent robotic single-incision anterior resection for sigmoid colon cancer at the Severance Robot and MIS Center in Seoul, Korea. The mean transumbilical incision length was 4.7 cm (range 4.2–8 cm) and there was no conversion to open surgery. The median operative time was 167.5 min (range 112–251 min); the mean length of stay (LOS) was 6 days (range 5–9 days). No perioperative complications were reported [2]. Our institutional experience includes 59 patients that underwent SIRC for both benign and malignant indications. Our incisions were approximately 3–4 cm long. Median operative time was 188 min (Interquartile range (IQR) 79 min) and median length of stay 4 days (IQR 2 days). There were 8 (13.6 %) conversions, including 4 (6.8 %) conversions to open procedures, 3 (5.1 %) conversions to multiport robotic procedures, and 1 (1.7 %) conversion to single-port laparoscopic procedure. Complications included six (10.2 %) incisional hernias, five (8.5 %) superficial surgical site infections (SSI), three (5.1 %) intra-abdominal infections, and one (1.7 %) postoperative stroke [8].

With limited literature on SIRC, our institutional experience found similar rates of postoperative complications as reported national averages for laparoscopic colectomies. To date, there is no comparative study between laparoscopic and robotic single-incision colectomy. Data from the American College of Surgeons National Surgical Quality Improvement Program Database (ACS-NSQIP) shows that 5.8 % of all sampled laparoscopic colectomies across the nation underwent conversion to open procedure. Increased age, obesity, and more severe comorbidities are associated with a higher likelihood of conversion to open procedure. The conversion rate with SIRC in large case series is approximately 6.8 %, which is similar to conventional multiport laparoscopic colectomy (9.9 %) or robot-assisted multiport laparoscopic colectomy (5.7 %) from a national surgical database [9]. Two of the largest SILC case series also reported similar conversion to open rate (5 %) reported by Ross et al. and 6.3 % reported by Vestweber et al. Data from the American College of Surgeons National Surgical Quality Improvement Program Database (ACS-NSQIP) shows that 5.8 % of all sampled laparoscopic colectomies across the nation underwent conversion to open procedure. Increased age, obesity, and more severe comorbidities are associated with a higher likelihood of conversion to open procedure [10]. Two most common reasons associated with SIRC conversion are (1) difficulty with visualization or exposure of narrow anatomic locations, and (2) equipment malfunction. Conversions, whether to multiport robotic procedure or open procedure, are associated with longer operative time, higher complication rate, and longer length of stay. While equipment malfunction should improve with technological advances and increasing familiarity with the instruments, it is important to focus on more preoperative stringent patient selection criteria to decrease chances of conversion. Risk factors for extensive organ adhesion such as past abdominal surgery, radiologic evidence of marked inflammation surrounding operative area or aberrant body habitus and anatomy structure should all be assessed before the decision to perform SIRC.

One of the criticisms of robotic surgery is the increased operative time, with some literature showing that it is mostly associated with the time spent on robot docking. Most of these studies are early case series from institutions starting out their robotic programs. Operative time in our case series for right hemicolectomy and sigmoidectomy are 180 ± 43 and 225 ± 65 min, respectively, which are slightly higher than those reported in Vestweber et al.'s LESS colectomy case series of 224 patients, with reported operative time of 142.3 ± 55.4 and 145.6 ± 47.5 min for right hemicolectomy and sigmoidectomy.

Conclusion

Single-Incision Robotic Colectomy is a unique technique allowing the surgeon to have 3D visualization, triangulation, and advanced wristed robotic instruments. With a small umbilical single incision, patients have better cosmesis and outcomes consistent with minimally invasive surgery. Single-institution studies have shown the safety and efficacy of the procedure. Larger studies are needed to further evaluate the technique.

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Chapter 20
Intraoperative Conversions in Robotic Colorectal Surgery

Matthew Skancke and Vincent Obias

Introduction

Robotics is quickly becoming the new gold standard for minimally invasive colorectal surgery, with recent studies showing shorter postoperative courses, decreasing operative times, and improved conversion rates when compared to laparoscopy [1–5]. Operative times currently appear to be longer with robotic colectomy, in part because most published studies are retrospective and typically clump actual operative time with docking and repositioning the robot. While prospective databases like ROLARR (NCT01736072) mature, it is important to note that early meta-analysis and single surgeon analysis have shown that operative times approach that of laparoscopy as surgeon and staff experience grow [5, 6]. The benefits of robotic colorectal surgery are especially apparent with rectal cancer and low pelvic dissections, as operative times and rates of conversion to laparotomy are superior compared to laparoscopy [7, 8].

Minimally invasive colorectal surgical operative times and conversion rates are important to consider, as studies have shown benefits versus laparotomy but diminishing returns in patient outcomes as operative time surpasses 180 min [9, 10]. In MIS and laparoscopy in particular, longer operative times are usually a result of five factors: excessive tumor fixity, anatomic uncertainty, tumor clearance, patient obesity, and surgeon experience [11, 12]. Recently published data from Canada citing approximately 500 robotic and 8400 laparoscopic colectomies demonstrated no difference in mean operative time (190 versus 187 min, respectively) and a significantly lower incidence of conversion to laparotomy in the robotic group (9.5 % versus 13.7 %, respectively) [13].

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With more than 30 % of the US population over the age of 20 having body mass index (BMI) values above 30 [14], the effects of BMI values on surgical outcomes have taken center stage. The visceral adiposity and larger abdominal wall can confound fine movements and make intraperitoneal manipulation of organs cumbersome. Multiple advanced laparoscopy studies have demonstrated direct links to complications related to obesity, including superficial and deep infections, longer operative times, and incisional hernia formation [15–17], as well as conversion from MIS to laparotomy [9, 18, 19]. Regarding infectious and hernia-related complications, the short-term outcomes of robotic colorectal surgery are similar to laparoscopy as BMI values increase [9, 18]. Other datasets suggest that while BMI values greater than 30 increase average operative times by up to 30 min, conversion rate, blood loss, leak rate, and overall complication rate are unchanged [13, 20, 21], supporting the claim that robotics are unaffected by BMI values. Resilience of robotic surgery outcomes to the effects of elevated BMI values is likely due in part to the fact that the robot mitigates the fulcrum effect of the trocar and the abdominal wall, stabilizing the instrument and camera and allowing for fine motion with minimal effort.

Generalizations can be made supposing that advanced tumors, prior radiation, and pathology resulting from inflammatory conditions like diverticulitis and inflammatory bowel disease lend themselves to increased anatomic fixity [22, 23] and increase the risk of unplanned conversion [13]. In fact, colon cancer (OR 1.810), Crohn's (OR 2.194), and diverticular (OR 1.980) disease were shown to be independent risk factors for unplanned conversion. Robotic surgery, however, was found to be protective against conversion versus laparoscopy (OR 0.713) for the aforementioned pathologic processes [13]. Interestingly, ulcerative colitis was not found to be an independent risk factor for unplanned conversion. Other studies have also shown viability of robotic completion proctectomy and ileal pouch anal anastomosis for ulcerative colitis [24, 25] with improved conversion rates but longer operative times when compared to laparoscopy [26].

As in the early days of laparoscopy, there is a learning curve associated with robotics. Early studies investigated single surgeon progression using cumulative sum analysis for the experienced colorectal laparoscopist and discovered three distinct phases: a learning phase when docking the robot is mastered, a plateau phase when the surgeon consolidates his/her skills and confidence, and an mastery phase when the surgeon expands case variety [27, 28]. Multiple smaller studies report that approximately 25 cases were required to reach the "mastery" phase. However, a significantly larger Korean single surgeon study concurred with the general findings of three stages of learning robotics, but cited initial phases of 35 cases, plateau phases of 93 cases, and mastery phases of 69 cases. It is important to note that the demographics of the later phases of the Korean study included lower rectal lesions and neoadjuvant chemoradiation, while the first phase was comprised of a statistically higher number of tumors more than 8 cm from the anal verge without chemoradiation [29]. Most importantly, none of the studies showed a significant increase in intraoperative conversion or complication rate as the surgeon progressed through phases one and two, suggesting that learning robotic colorectal surgery does not place the patient at undue risk.

Specific Topics

Pneumoperitoneum

Carbon dioxide (CO_2) is the medium currently used to establish insufflation for MIS due to its stable combustion profile and its ability to be physiologically absorbed in tissues and subsequently expelled in the lungs of healthy patients. Along these lines, most contraindications to pneumoperitoneum revolve around inability to tolerate increased abdominal pressures and an inability to absorb and excrete CO_2 in the lungs. As with laparoscopy, complications that arise from establishing pneumoperitoneum are usually resolved by evacuation. In these cases, it may be wise to discuss the patient's condition with the anesthesiologist and consider delaying the procedure or proceeding with laparotomy in cases of emergency.

Capnothorax is a phenomenon caused by insufflation of the thorax with CO_2. In colorectal surgery this is usually from micro/macroscopic defects in the diaphragm and can ultimately lead to tension pneumothorax physiology [30]. Pathologically, this manifests as hypercarbia and decreased cardiac output. The body attempts to correct by increasing expulsion of CO_2 by increasing cardiac output and thus pulmonary blood flow but is unable to given decreases in preload from the increased intrathoracic pressure [31]. Visually this can be verified by caudal displacement of one or both hemidiaphragms with absent or decreased breath sounds in the affected hemithorax.

Management is based on the clinical significance, which is stratified by a drop in systolic pressure between 15 and 35 mmHg, increased airway pressures, $PaCO_2$ greater than 50 mmHg, or SpO_2 less than 95 % [30, 32–34]. When these conditions are met, immediate evacuation of pneumoperitoneum with concomitant surgical evacuation of the affected hemithorax should be performed. Following hemodynamic stabilization, the operator may attempt reinsufflation but should entertain conversion to laparotomy. Conversely, capnothorax without hemodynamic compromise can be managed with observation and usually resolves shortly into the postoperative period [34, 35].

CO_2-related embolic events occur rarely (15 per 100,000 per year in laparoscopy) and are usually heralded by sudden hemodynamic collapse with decreased end-tidal CO_2 and decreased chest compliance. Physiologically this occurs from CO_2 accumulating in the right ventricle or in the pulmonary arterial system, causing a "gas lock," and preventing forward flow of blood [36]. The remedy is placing the patient in the Trendelenburg position, with subsequent placement of a central venous catheter and aspiration of the air from the right side of the heart. Prophylactically, this can be prevented by ensuring adequate resuscitation in the preoperative phase. This condition is traditionally seen with liver resection, given the caliber of the venous sinuses; however, occurrences following manipulation of sacral plexus veins have also been reported [36, 37].

Robotic Malfunction

As with any complex machine, mechanical and software failures do occur. Between 2000 and 2013 of 1,745,000 robotic procedures performed in the United States across multiple surgical specialties, an estimated 10,624 adverse events (0.6 %) were related to malfunction reported using the MAUDE database [38]. Of these 10,624 incidents, 1535 had clinically significant patient outcomes including injury (1391) and death (144). By comparison, there is little reported regarding the failure rate of laparoscopic instruments. The malfunctions included video/imaging (7.4 %), broken/burnt pieces falling into the patient (14.7 %), electrical discharge (10.5 %), unintended instrument action (10.1 %), and other issues with "electrosurgical units, power supplies/cords, patient side manipulators, etc." Fortunately, approximately 10 % of these malfunctions were identified prior to beginning surgery and the case could be delayed/rescheduled. Other large multi-institutional urologic reports cite a critical failure rate of 0.4 %, leading to case cancellation in 24 cases and conversion in 10 cases out of 8240 [39]. Single institutional studies cite a total malfunction rate of 2–4 % with a robotic system failure rate of less than 2 % (excluding instrument failure) and a need for resulting conversion of less than 1 % [40–42].

Focusing specifically on mortalities associated with robotic surgery in this particular report, 17 % of the 144 reported deaths occurred during the procedure itself while 75 % in the postoperative period. Intraoperatively, less than ten deaths were related to inadvertent damage to organs, while the rest were secondary to uncontrolled bleeding and cardiopulmonary pathology. Overall, 50 % were reported as risk inherent to the procedure, 11 % as underlying medical disease, and 7 % as surgeon/staff mistakes [38].

Based on the nature of the malfunction, the *da Vinci*® System classifies the faults as recoverable (yellow light on instrument) or nonrecoverable (red light on instrument). When faults occur, all robotic arms are locked and can be moved by clutching, but require additional effort to do so; for nonrecoverable faults, the offending instrument must be removed from the body and the robot must be restarted; undocking is not required. Conversely, recoverable faults can be overridden on the surgeon's console.

The console allows the operating surgeon to disable certain arms if isolated faults occur, but the camera cannot be controlled from the console after it has been disabled from the master control. If an emergency stop (on right side of console) is required, all instruments and the camera will remain in their last reported positions, and mechanical force on grasping devices will decrease. An emergency stop constitutes a recoverable fault and can be overridden on the surgeon's console [43].

When instrument failures occur, the grip of the device may need to be manually released. This process begins with visualizing the offending instrument and then initiating an emergency stop. The grip release tool is then inserted onto the anterior portion of the device housing and turned clockwise for clip appliers and harmonic devices and counterclockwise for other instruments. The offending instrument can then be moved to a safe location and removed in the standard fashion. If the robotic arm is providing temporary hemorrhage control or critical visualization, an emergency stop can be initiated and the surgeon can leave the console and convert to laparotomy around the current instruments [43].

Reoperation and Adhesions

Anecdotally, the benefits of robotic surgery for complex revisional surgery and adhesiolysis center around a fusion of the hardware and software capabilities of an inorganic operating platform. Foremost, the robotic interface provides a stable camera and axis of control allowing the surgeon to perform fine movements. Wristed instrumentation then provides additional degrees of freedom, while robotic servos negate muscle fatigue and facilitate unwavering exposure, enabling the surgeon to perform prolonged adhesiolysis. Comparatively, muscle fatigue and fine tremor in laparoscopy is translated over the entire length of the instrument and becomes clinically significant during prolonged dissection.

With more than 95 % of abdominal surgeries leading to future adhesions and 10–20 % of individuals requiring additional surgical procedures following a colorectal or general abdominal surgery, intraabdominal adhesive disease is a regular obstacle for the colorectal surgeon [44]. Intuitively, adhesions make subsequent dissection more precarious, decreasing the quality of the resection and increasing overall morbidity [45, 46]. Other studies report an almost 15 % increase in major surgical-related complications in patients requiring adhesiolysis, but no decrease in the quality of the oncologic resection [47].

Data on robotic adhesiolysis for colorectal surgery is lacking. However, revision surgery for bariatrics touts the robotic platform for its ease of dissection around the gastric pouch, a step of the procedure known for its complexity [48]. Literature for robotic-assisted urologic surgery in patients with prior abdominal surgeries similarly indicates no differences in outcomes for those without prior abdominal surgery [49, 50]. Gynecologic studies have, however, shown a direct benefit for robotic surgery versus laparoscopy for cases with severe adhesive disease regarding operative time, blood loss, and clavien-dindo classified complications [51]. In this particular study, conversion rate was also 3 % less than laparoscopy for severe adhesive disease but lacked the power for significance.

Intraoperative Complications

Intraoperative complications can occur regardless of surgical skill, patient selection, or operative preparation. Aside from a failure to progress, iatrogenic injuries in colorectal surgery warranting conversion usually include large volume hemorrhage, unplanned enterotomy, and anastomotic leak. Hemorrhage and enterotomies in robotic surgery are usually secondary to traction injury or unintended injury from nonvisualized arms. Traction injury may be a result of the lack of haptic feedback in robotic surgery, as visual cues alone are no replacement for the direct sensation provided in laparotomy and laparoscopy. Large volume hemorrhage is usually from named vessels or named venous plexi and can be managed robotically with bipolar cautery or intracorporeal suture ligation. In these cases surgical skill and visualization will dictate the rate of conversion to laparotomy. Much like with vascular injury, the increased dexterity of the robot also allows enterotomy or anastomotic leak to be repaired primarily without mandating conversion to laparotomy.

Robotic Stapling

The development of the robotic stapler has allowed for a completely intracorporeal dissection, resection, and anastomosis, but does not obviate complications related to the lack of haptic feedback. With laparotomy and laparoscopy, the operator is able to gauge the thickness of the tissue based on its resistance to compression and can modify his/her position or stapler load. Instead, robotic surgery relies on stapler clamp completion through *SmartClamp*™ technology [52]. With *SmartClamp* technology, the robotic *EndoWrist*® stapler provides precise, computerized feedback to detect whether the jaws are adequately closed on the target tissue for the selected load color prior to firing. Over the past 2 years, field data for stapler firings of the *da Vinci* robotic stapler (Intuitive Surgical Inc., Sunnyvale, CA, USA) showed that greater than 80 % of the time, users achieved a successful clamp on the first clamp attempt; this improved to greater than 90 % on the second successive clamp. If clamping is unsuccessful after the second attempt, repositioning the stapler or upsizing to a load designed for thicker tissue is recommended. Successful clamp rates continue to improve each quarter as the surgical community gains more precise feedback and training on proper use. The same dataset also sampled stapler loads for low anterior and right colon resections and showed that there was no "best" stapler load for rectum versus colon and that 40 % of the time, surgeons used a combination of different loads in the same case [53].

Conclusion

Robotic colorectal surgery continues to gain momentum as the field matures, and with continued development on the hardware and software side, the future of robotic surgery is bright. However, despite the benefits afforded by a robotic implementation, there will be times when conversion to laparotomy is indicated to maintain an acceptable safety profile. The prepared surgeon will be well equipped to mitigate these complications robotically, especially in the pelvis, but should not be recalcitrant in delaying conversion to laparotomy if control cannot be quickly reestablished.

Key Points

- Robotic colorectal surgery in the pelvis has shorter operative times and lower conversion rates compared to laparoscopy.

- A stable operating platform, a shorter axis of movement, and an operative fulcrum supported by the robot allow for precise dissection throughout the abdomen.
- Obesity and adhesive disease have an attenuated impact on robotic surgery compared to laparoscopy.

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Chapter 21
Current and Future Platforms for Robotic Colorectal Surgery

Jeffrey N. Harr and Deborah Nagle

Introduction

The use of robot-assisted surgery has dramatically increased over the last decade and is now being employed in virtually every surgical specialty. The appeal of robotic-assisted surgery is improved vision, accuracy and precision, favorable surgeon ergonomics, as well as dexterity with wristed instruments in minimally invasive procedures. However, the vision of robotic surgery has shifted since its early development in the late 1980s. Originally, the use of robotic platforms was being explored in specific urological and orthopedic procedures to increase precision and accuracy, but it did not take long before the concept of "telepresence" surgery gained traction [1]. Large-scale research began under the Defense Advanced Research Projects Agency (DARPA) to remotely use robotic technology to save soldiers wounded on the battlefield. However, an inappropriately long latency period of 1.2 s, from the movement of the controls on the workstation until the signal arrived at the manipulator, significantly degraded the accuracy of tasks. However, location-specific robotic platforms do not have this limitation. Therefore, the clinical realization of robotics was to improve upon the limitations of laparoscopic surgery (loss of three-dimensional visualization, less stable handheld camera platform and limited dexterity) which led to successful commercial development of the technology. Currently, there is only one corporation, Intuitive Surgical, Inc, with FDA approval

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for conducting business with clinical devices. Intuitive, Inc. dominates a roughly $5 billion annual market for robotic surgery platforms. However, global annual medical robotic revenues are expected to grow to $20 billion by 2020.

Robotics were first used in colorectal surgery in 2002, and since then, have become increasingly popular due to the technologic advances that overcome the limitations of laparoscopic surgery [2]. The high-definition, three-dimensional camera provides a stable, magnified view. The wristed, surgical instruments allow for precise dissections, especially in the deep pelvis. The robotic platform allows for self-retraction and improved ergonomics. Near-infrared technology enables real-time identification of structures and tissue perfusion. And furthermore, the estimated learning curve is approximately 20 cases, even for surgeons who lack significant laparoscopic experience [3]. Despite these benefits, there has been some pushback in the surgical community cautioning against the widespread adoption of robotics, stating increased operative times and costs, delayed response to complications from not being at the bedside, lack of haptic feedback, and no significant difference in outcomes compared to laparoscopic surgery. Adequate studies to address these issues are still lacking, but with upcoming technological advancements and improved robotic surgery platforms, future studies may find robotic-assisted surgeries to be superior to standard laparoscopy in colorectal procedures regarding costs, complications, and outcomes.

Limitations of Current Robotic Surgery Platform

Currently, the only Food and Drug Administration (FDA)-approved robotic platform for abdominal surgery is the da Vinci system (Intuitive Surgical, Inc., Sunnyvale, CA). The da Vinci Si and Xi systems are currently available and have a substantial footprint requiring large operating rooms. The platform consists of three components including the surgeon console, the patient cart, and the vision system cart. Together, these components weigh over 1000 pounds and are connected by optical cables either lying on the floor or integrated into the operating room walls or booms. Additionally, this platform may cost approximately $1.2–$2.5 million, depending on the Si or Xi platform, number of surgeon consoles, and simulator options purchased, as well as an annual maintenance cost of approximately $100,000–$340,000 making it cost prohibitive for some hospitals [4]. Although the upfront expenditures of purchasing the da Vinci system contribute to most of the increased costs of robotic-assisted surgeries, the cost of robotic instruments with limited life spans may also add to increased operating expenses. The costs of the disposable or limited-use instruments are approximately $220 per instrument use [4].

Another limitation is the lack of haptic feedback. In open cases, surgeons rely on haptic feedback in palpating structures; to discern tension on tissue; and grasping tissue, sutures, or needles. With the current da Vinci platform, surgeons cannot discern tactile and force feedback, and solely rely on visual feedback, which may lead to inadvertent injuries and complications. Several studies have demonstrated improved effectiveness in tissue characterization and discrimination with haptic feedback, but there is currently no evidence that haptic feedback will decrease robotic-assisted complications [5–7]. However, it may help further decrease the learning curve for surgeons transitioning from primarily open surgeries to minimally invasive approaches. To address these limitations, Intuitive as well as many other upcoming companies are developing new technologies and robotic platforms.

Upcoming Surgical Platforms

Intuitive Surgical, Inc.

The fourth-generation Xi da Vinci has made significant changes to the third-generation Si platform (Fig. 21.1). The patient cart has a rotating boom that allows for accurate positioning toward the target anatomy, regardless of the bedside location, and also

Fig. 21.1 da Vinci Xi patient cart

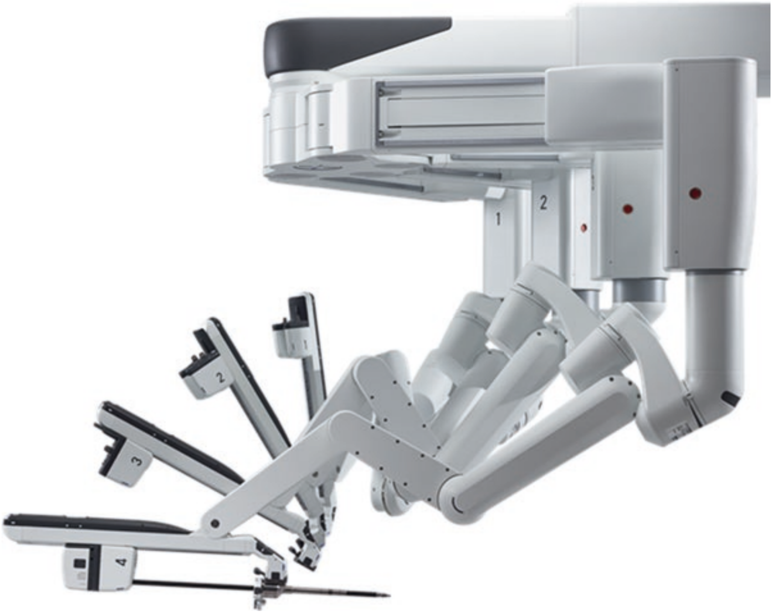

Fig. 21.2 da Vinci Xi robotic arms

allows for quick docking and undocking for surgery in multiple quadrants. Additionally, the robotic arms have a lower profile allowing for smaller distances between port sites, which also reduce arm collisions (Fig. 21.2). The robotic camera is also smaller, lighter, can be used in any robotic arm, and can easily flip from a 30° up to a 30° down position from the surgeon console. Together, these advances allow for increased maneuverability for work in multiple quadrants, especially important in colon and rectal surgery, and minimize camera exchanges and docking.

As a complement to the Xi platform, Intuitive will soon release the SP patient cart (pending FDA approval), which will be the next generation of single port surgery. A flexible high-definition, 3D camera and three flexible robotic arms can be placed through a single 25 mm trocar. This will address several of the limitations of the current single-port system for the Si platform, which requires special curved trocars and instruments, and lacks wristed instrumentation. Furthermore, with the SP's increased instrument length and flexibility, it may be ultimately docked in a suprapubic location and can reach all abdominal quadrants. Until the SP platform is approved, new wristed instruments and port system will soon be available for the Xi platform, improving the more rigid Si single-port system.

Currently, there is no on-label single-port system specific for colorectal surgery. Right hemicolectomy with an extracorporeal anastomosis has been performed with the current Si single-site system, but this operation is tedious and relies heavily on the bedside assistant for retraction and applying clips for control of mesenteric vessels. However, with surgical gloves or gel-port devices, a makeshift single-site port can be fashioned for Si and Xi cameras and instruments, including the robotic stapler, making single-site colorectal surgery a more feasible option. Right and left colectomy, sigmoidectomy, low-anterior resection, and total abdominal colectomy have all been performed with this method [8]. Additionally, robotic-assisted transanal surgery has been performed with these methods including excision of low rectal polyps and malignancies, as well as transanal total mesorectal excision [9–11]. With the addition of the da Vinci SP platform some of the technical challenges of transabdominal single-incision colorectal surgery and transanal surgeries will be addressed, decreasing the learning curve for these complex procedures and possibly increasing adoption of the techniques.

TransEnterix

The SurgiBot™, by TransEnterix, is currently under development, and is preparing for FDA approval [12]. This robotic platform offers a bedside robotic cart and a vision cart, which employs a 3D high-definition monitor (Fig. 21.3). This allows the surgeon to remain at the patient's side in a sterile field and also provides a portable 3D experience

Fig. 21.3 SurgiBot™ Bedside cart and vision console

Fig. 21.4 SurgiBot™ articulating arms and camera

for everyone in the operating room wearing 3D glasses. The footprint is therefore smaller than the da Vinci system and offers more mobilization in smaller rooms. The SurgiBot™ is designed with a focus on single-port surgeries, which utilizes a midline camera and two articulating robotic channels, in which flexible instruments can be robotically controlled (Fig. 21.4). Flexible and catheter-based instruments can also be passed through a third channel for additional assistance. Laparoscopic handles are used to control the instruments, giving a familiar experience to laparoscopic surgeons, but lack the wristed motion of the da Vinci platform. However, this platform does provide tactile feedback providing added instrument control. Additionally, the SurgiBot™ allows for multiquadrant movement without having to undock and dock the robotic cart from the patient. Advanced energy devices including Flex Ligating Shears and a monopolar hook have recently been developed. Other instruments currently available for this platform include a wavy grasper, Maryland dissector, Flex shears, suction irrigator, fenestrated grasper, clip applier, and a needle driver. For this platform, stapling will need to be performed extracorporeally or a stapling device will have to be inserted through a separate trocar site. Currently, preclinical studies have shown success with this platform in single incision cholecystectomies and nephrectomies in porcine models. Although no specific colorectal use has been marketed, the single-site platform and ability to work in multiple abdominal quadrants make the SurgiBot™ a plausible option for colorectal and likely transanal surgeries.

Titan Medical Inc.

Titan Medical Inc. was known to be working on a multiport robotic platform but appears to have shifted resources to a single-port platform in order to appeal more to general surgery and other specialties underserviced by current robotic devices [13]. The SPORT™ (Single Port Orifice Robotic Technology) surgical system consists of a surgeon workstation and a single-port patient cart. This platform has a high-definition

3D camera and two flexible robotic arms, which can fit through a 25 mm port. The SPORT™ surgical system will have disposable instruments, which currently include a curved dissector, hook cautery, needle grasper, and an atraumatic grasper. The benefit of the SPORT™ surgical system will be a smaller footprint and lower cost (<$1.0 million) compared to the da Vinci platform. However, the disadvantages will be the need for additional ports for separate laparoscopic vessel sealers, stapling devices, and clip appliers. Furthermore, there have been no reports about the incorporation of haptic feedback. Titan Medical Inc. has estimated a release date in Europe in 2016, and a United States release date in mid-2017 pending FDA approval. Similarly to the SurgiBot™, the SPORT™ surgical system may have a role in single-port colorectal and transanal procedures at a reduced cost to other platforms.

SOFAR S.p.A

The Telelap ALF-X is a new advanced platform for minimally invasive surgery developed in Italy by the pharmaceutical company SOFAR S.p.A [14]. It also provides a high-definition 3D camera, which can be used in any robotic arm, as well as an ergonomic surgeon console with a 3D monitor. The surgeon console, or “surgical cockpit,” also employs laparoscopic instrument handles, providing familiar instrument handling to laparoscopic surgeons (Fig. 21.5). The platform is unique in that

Fig. 21.5 Telelap ALF-X surgeon console

Fig. 21.6 Telelap ALF-X bedside robotic carts

individual bedside carts control one robotic arm each, and 3–4 arms can be connected to 1–2 surgeon consoles through a connection node cart (Fig. 21.6). Subsequently, this requires a larger footprint in the operating room but offers other benefits. This includes quicker docking (which takes seconds), fewer arm collisions, more accurate movement of surgical instruments, and the ability to operate in multiple abdominal quadrants without undocking and redocking. Each arm provides 6 degrees of freedom in movement and instruments attach to the arms with magnets, allowing for quick and uncomplicated instrument exchanges. It is also more assistant friendly for the attachment and replacement of surgical instruments and provides an uninhibited view of and easy access to the surgical field. Another potential advantage of the Telelap ALF-X is the haptic feedback features, which enable the perception of the consistency of tissues and the forces exerted. An eye movement tracking system allows the surgeon to control the camera by moving any point looked at to the center of the screen. The eye-tracking system also enables the activation of the various available instruments by just looking at their respective icons on the screen. In addition, standard laparoscopic trocars can be used, and a fulcrum search application adjusts the most appropriate insertion instruments to minimize local stress and trauma on the surrounding tissue. Telelap ALF-X also offers a wide range of reusable instruments and adapters, which can be sterilized by autoclave (Fig. 21.7). Monopolar and bipolar energy devices are currently offered, but vessel-sealing devices are now under development and will be available in the near future. SOFAR S.p.A also suggests the cost of the platform to be two-thirds that of the da Vinci platform. With a less expensive platform and reusable instruments, costs are close to standard laparoscopic surgery. The Telelap ALF-X platform provides many benefits of other robotic platforms for colorectal surgery, including easier multiquadrant operations, but also offers more advanced technological features such as haptic feedback and an eye-tracking system. However, the individual arm carts may inhibit the use of this platform for transanal

Fig. 21.7 Telelap ALF-X reusable instruments

surgeries and might require a larger operating room spatial footprint, limiting the areas of its use. Furthermore, laparoscopic stapling devices are needed, but may be easier for assistants to use with increased access to the surgical field. Currently, the Telelap ALF-X platform is only marketed in the European Union, but there are plans to apply for FDA clearance and market in the United States in the near future. SOFAR S.p.A may integrate with TransEnterix to accomplish this goal.

Telesurgery

The technological advancements in robotic surgery have made the idea of telesurgery a reality. With telesurgery, patients can acquire unique surgical expertise despite being great distances from highly specialized surgeons. The military has envisioned the use of telesurgery in forward operating bases near combat zones with limited medical staff. If telesurgery could be employed in civilian life, it could allow advanced surgical care in any region with limited resources including rural communities, third world countries, and even the international space station. However, implementation of telesurgery has been limited due to data transmission latency. Once cables are no longer used to connect the surgical console to the robot, the data must be compressed, transmitted, and then uncompressed at the receiving location. This creates a latency period, which can degrade surgical performance. Studies have revealed that basic tasks can be satisfactorily performed with up to a 600-ms time delay, but complex procedures have a significant increase in errors with delays greater than 300 ms [15–17]. Despite the issue with latency, Jacques Marescaux of Strasbourg, France performed the first transatlantic cholecystectomy on a patient in Strasbourg while sitting on a surgical console in New York City in 2001 [18]. Currently, telementoring is being employed allowing for colorectal surgeons to provide real-time intraoperative feedback during complex cases, but latency times and medical–legal factors have dissuaded telesurgery use in the United States. Although still limited, telesurgery continues to be explored.

Stanford Research International (SRI), who has helped pioneer robotic surgery platforms from the 1980s under contract to the U.S. Army and funding from the NIH, developed the M7 surgical robot in 1998 [19]. The current version has two anthropomorphic robotic arms, which move through 7 degrees of freedom, and in which conventional surgical tools can be swapped rapidly by a technician. The advantage of the M7 not offered by other platforms is the incorporation of auditory, visual, and tactile sensations, as well as haptic feedback. Additionally, the robotic platform software compensates for jarring or turbulence on a moving platforms (such as in vehicles, aircraft, or in space) virtually eliminating tremor. In 2006, the M7 successfully completed a real-time abdominal surgery on a patient simulator remotely in the Aquarius Underwater Laboratory 60 ft underwater off the coast of Key Largo, Florida as part of the ninth NASA Extreme Environment Mission Operations [20]. Similarly, in 2007, the M7 was used to complete basic exercises aboard a NASA C-9 aircraft simulating the microgravity of space [21]. The M7 was also used to perform the first automated ultrasound-guided tumor biopsy [20].

Another robotic platform focusing on telesurgery is the Raven, developed by physicians and scientists at the BioRobotics Laboratory affiliated with the University of Washington in 2005, and is sponsored by the Department of Defense [22]. The current version of the robot (Raven II) weighs 22 kg, and has two articulated, tendon-driven arms in which different surgical instruments can be easily exchanged. It can be easily disassembled/assembled for transport by nonengineers, and the communication links have been designed for long-distance remote control. The unique feature of this platform is that the Robot Operating System software contains a popular open-source robotics code, allowing other labs and researchers to connect the Raven II to other devices and share ideas. Other robotic labs including Harvard, Johns Hopkins University, the University of Nebraska-Lincoln, UCLA, and UC Berkeley have also received Raven II robots to further research and problem-solve the current limitations of robotic surgery. The Raven II has also been tested in underwater NASA training habitats, remote desert locations, unmanned aerial vehicles, as well as zero-gravity astronaut training drills [23–26].

Robotic Endoscopy

The gold standard for the diagnosis of colon and rectal disease is video-colonoscopy. This allows for direct visualization, tissue sampling for diagnosis, and interventions. However, the invasiveness of this technique, as well as patient discomfort requiring sedation, poses limitations. Subsequently, robotic platforms for colonoscopies have been proposed to address these limitations. These platforms reduce pain and possibly the risk of perforation by minimizing excessive stretching of the bowel, by limiting air insufflation and reducing the pushing action exerted by the endoscopist. These devices also are more flexible, which decreases the distortion of the colon and also allows for a more comfortable and safer procedure. Present devices are currently not employed clinically in the US, and have limited, if any, interventional capabilities. However, the next step in technological advancement is the addition of interventional capabilities, as well as with adding its concurrent use into laparoscopic/robotic colorectal operations since current standard intraoperative colonoscopies are burdensome due to excessive insufflation and colonic distortion.

Soft Colonoscopy Robotic Platform

The Vanderbilt STORM (Science and Technology of Robotics in Medicine) Lab has further developed the magnetic air capsule system first introduced by Dr. Valdastri [27]. This platform navigates an endoscopic capsule through magnetic coupling, which pulls the capsule through the colon, as opposed to a traditionally pushed endoscope, which stretches the colonic wall generating pain [28, 29]. This device is a tethered capsule that contains an endoscopic camera, white light LEDs, a therapeutic tool channel, and air/water channels for insufflation and cleaning. The camera has a 550×582 pixel resolution and a 120° field of view. The small size of the capsule and the soft, flexible tether increases patient comfort, minimizing sedation. The robotic platform uses an external permanent magnet connected to a 6 degrees of freedom robotic arm with a 7th custom-degree of freedom at the end-effector increasing dexterity to maneuver the endoscopic capsule. The robotic arm is controlled by an input device and joystick, which interacts with a real-time motion control system and provides haptic feedback. This technology theoretically can reduce the physical demands of performing the procedure, expand the pool of medical personnel able to operate the system, and may allow for tele-endoscopy in rural areas or for military personnel overseas. Currently, this device is not on the market, but preclinical studies have demonstrated feasibility and accuracy compared to conventional colonoscopy [29].

Endotics

The Endotics (Era Endoscopy S.r.I) robotic platform was developed in Italy and uses a computer-assisted propulsion system with locomotion similar to that of an earthworm [30]. The Endotics system is composed of a sterile, disposable probe and a workstation (Fig. 21.8). The head of the probe contains a steerable tip, a vision system with a CMOS camera and LED light source, and channels for a water jet and air, as well as an instrument channel (Fig. 21.9). The body of the probe is highly flexible, conforms to the shape of the colon, and contains two vacuum-mechanical clampers that are located in the proximal and distal part of the probe. The locomotion is achieved by the coordinated adherence and release of the

Fig. 21.8 Endotics workstation

Fig. 21.9 Endotics disposable probe

clampers to the colon mucosa and is operated by a handheld controller similar to those seen with home gaming systems. For locomotion, the operator can steer the head of the probe 180° in every direction, and then activate the forward or backward motion through an automated series of steps: the proximal clamper adheres to the mucosa and the central part of the body is elongated; the distal clamper adheres to the mucosa and the proximal clamper is released; the central part of the body is contracted so that the proximal clamper may adhere to the mucosa; and finally, the distal clamper is released. This sequence is repeated several times allowing the probe to move in a worm-like fashion [31]. This clamping mechanism is safe and does not produce bowel wall lesions or mucosal lacerations. Early clinical studies have shown an equivalent diagnostic accuracy to the standard colonoscope, with a sensitivity of 93.3 %, and a specificity of 100 %, and no patients requested or required sedation [32, 33]. Benefits of this system are that it is safe with the disposable probe, eliminating the risk of cross-infection, and that it is cost effective since it eliminates costs related to perforation, cross-contamination, work-related injuries, sterilization and sedation, and decreases room turnover time. Furthermore, the company touts a fast learning curve with the intuitive handheld controller. However, the main limitation currently is increased colonoscopy times.

GI View Ltd.

The Aer-O-Scope™, introduced by the Israeli company GI View Ltd., uses a self-propelled pneumatic intubation system by employing balloons and low-pressure CO_2 gas, and exerts ten times less pressure on the colonic wall than the standard colonoscope [34]. The Aer-O-Scope™ consists of disposable scanner, which contains an imagining capsule with a CMOS camera, and a soft, flexible cable containing channels for air, suction, and a water jet (Fig. 21.10). The imaging system provides two simultaneous views for visualization of the colon, including a standard forward-looking view, as well as a 360° "omni-view" providing visualization ahead of the capsule, behind the

Fig. 21.10 Aer-O-Scope™ disposable probe and optical head

Fig. 21.11 Aer-O-Scope™ workstation

capsule, and of all sides of the capsule, increasing visualization behind haustral folds, and subsequently, polyp detection rates. The disposable scanner connects to a PC-based workstation, which is equipped with an ergonomic joystick that controls navigation, insufflation, irrigation, and suction (Fig. 21.11). The computer-assisted platform receives and processes transmitted pneumatic controls and pressure measurements within the camera and scanner to safely advance and withdraw the Aer-O-Scope™ within the colon lumen. The Aer-O-Scope™ has recently received FDA 510(k) clearance and is expected to be introduced in the United States in 2016. The advantages of this system are with the single-use endoscope preventing cross-contamination, the low-pressure pneumatic propulsion, and the 360° visualization of the colon. The handheld joystick has an intuitive design, decreasing the learning curve, and allowing physicians to be trained in half a day [34]. Currently, there is no published data on the cost of the system or the cost effectiveness compared to traditional colonoscopy, but is expected to reduce costs by decreasing complications, allowing for quicker room turnover, and increasing polyp detection. Also, there is no published data on sedation requirements. Another limitation is the lack of a working instrument channel for biopsies and interventions. However, the low-pressure CO_2 propulsion system and visualization capabilities would offer several advantages for intraoperative colonoscopies.

Conclusions

Robotic surgery is a rapidly evolving field, driven by technological advances and end user enthusiasm. It is not yet clear whether the proposed advantages of robotic surgery are durable and meaningful. Thoughtful clinical analysis, best answered with randomized clinical trials, is difficult to structure into practice prior to technical advances. Therefore, the real benefits of robotic surgery, whether to patient, surgeon, or both, are not yet clearly identified. As always, well-designed studies, ideally randomized, will hopefully clarify these issues but may not be performed prior to widespread adoption of the technology.

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